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Studies of
ELECTROCHEMICAL ACTION IN THE
ORAL CAVITY

by

Krister Nilner



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ELECTROCHEMICAL ACTION IN THE ORAL CAVITY

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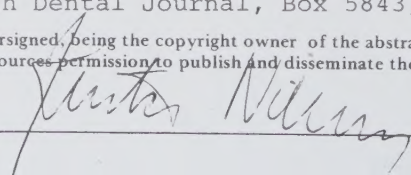
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Abstract A method for in vivo measurements of potentials and polarizations of metallic dental restorations was presented. The precision of this method allowed for calculation to be made of the electrochemical action in the oral cavity in terms of currents created at contact between metallic restorative materials. With this method, an epidemiological investigation was performed on persons, who had received dental treatments including extensive metallic restorations. Those persons suffering from oral symptoms allegedly caused by oral galvanism were not found to have higher electrochemical action in the oral cavity than persons, selected as a control, without symptoms ascribed to oral galvanism. Persons ailing from this type of symptoms showed, however, lower threshold levels for electric stimulation, examined with an electrogustometric method, than persons without symptoms. Finally, determination of the saliva concentrations of various metallic components with atomic absorption spectrophotometry did not reveal any differences between persons with or without metallic restorations. Neither were any correlations found between saliva ion concentrations and the magnitude of currents created at metallic contact between dental restorations.			
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by

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Malmö 1981

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PREFACE

This thesis is based on the following papers, which will be referred to by their Roman numerals.

I. Bergman, M., Ginstруп, O. & Nilner, K.

Potential and polarization measurements in vivo of oral galvanism.

Scand. J. Dent. Res. 1978, 86, 135 - 145

II. Nilner, K., Glantz, P-O. & Zöger, B.

On intraoral potential- and polarization measurements of metallic restorations.

A methodological and time dependent clinical study.

Acta Odontol. Scand. In press

III. Nilner, K., Glantz, P-O., Ryge, G. &

Sundberg, H. Oral galvanic action after treatment with extensive metallic restorations.

Acta Odontol. Scand. In press

IV. Nilner, K. & Nilsson, B. Intraoral currents and taste thresholds.

Swed. Dent. J. In press

V. Nilner, K. & Glantz, P-O. The prevalence of

copper-, silver-, tin-, mercury- and zinc-ions in human saliva.

Swed. Dent. J. In press

EXPRESSIONS

Throughout this study the expression certain oral symptoms has been used. This understands that one or more of the following symptoms (*Lain & Caughron 1936*) were present:

Burning mouth

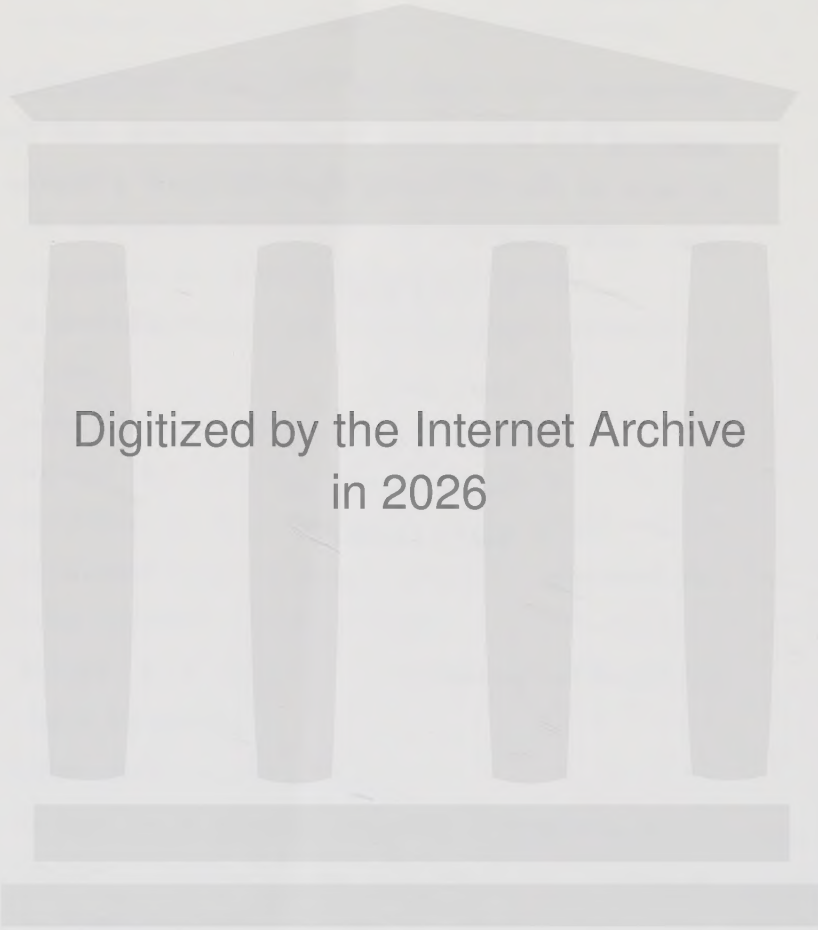
Oral pain

Oral smart

Battery taste

Metal taste

Salty taste



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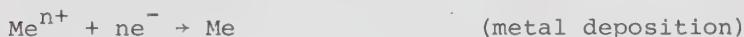
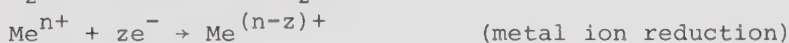
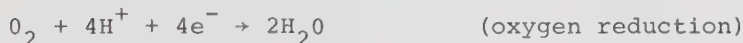
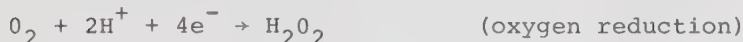
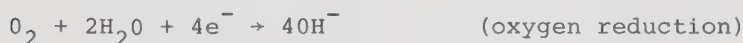
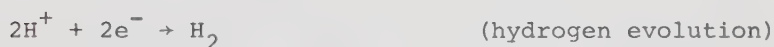
INTRODUCTION

When exposed to conditions present in the oral cavity metallic restorations and appliances are subjected to corrosive processes. Besides causing damage to the restorations and appliances (*Jørgensen 1955, Angmar-Månsson, Ommell & Rud 1968, Frykholm & Hedegård 1968 and Rud & Ommell 1970*), these processes create currents. The galvanic currents result from electrode reactions which can be summarized as follows:

anodic reaction:



cathodic reactions:



For further studies of these and other electrochemical reactions see Gellings (1976).

As secondary phenomena to oral corrosive processes, a number of local and general biological reactions have been discussed (*Solomon, Reinhard & Goodale 1933, Charpy 1952, Schriever & Diamond 1952, Mumford 1957, Inovay & Banoczy 1961, Gasser 1968 and Frykholm, Frithiof, Fernström,*

Moberger, Blohm & Björn 1969).

The biological effects of the currents created have been particularly discussed by Schriever & Diamond (1952) and Mumford (1957, 1960), who have all pointed to the possibility of these currents causing local oral discomfort and pain.

In dentistry, defined currents have been used for certain diagnostic purposes in endodontics (*Björn 1946 and Mumford & Björn 1962*) and at screening of physiological taste threshold levels (*Nilsson 1978*).

To obtain information about the incidence and magnitude of electrochemically created intraoral currents, direct or indirect measurements have to be taken. A number of methods for laboratory estimations of such currents have been presented (*Fusayama, Katayori & Nomoto 1963, Todorov 1968, von Fraunhofer & Staheli 1972, Lukas 1973, Sarkar & Greener 1973 and Arvidson & Johansson 1977*). Due to the extremely complex and varying conditions in the oral cavity, it is, however, difficult to create clinically relevant conditions during in vitro-experiments.

Bearing the above-mentioned in mind it was considered of interest to design a method for such in vivo-measurements to be taken, that allow for valid current levels to be determined, to use this method in an epidemiological study of a population with metallic restorations, and to estimate the possibilities for oral galvanic currents to cause certain local and general biological reactions.

MATERIALS AND METHODS

I. A detailed description of the equipment used is given in Paper I, and a sketch of it is shown in Fig 1.

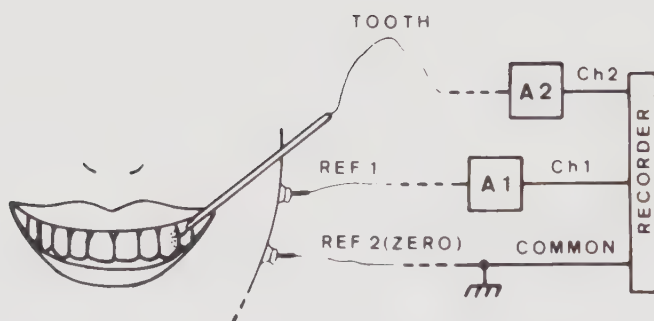


Fig 1. Principal sketch of experimental set-up.

Briefly two reference electrodes were attached to the patient's cheek; one served as a zero point for the voltage measurements and the other had a supervisory function. A platinum tip was used to establish contact with the metallic restorations. The voltages were recorded on a W & W Dual Channel Recorder, Series 1200 (W & W Electronics, Basel, Switzerland), after passing the electronic devices A1 and A2.

A current of either 1 μ A or 10 μ A could also be momentarily introduced into the platinum electrode (input marked "tooth"). This current flowed into the metallic restoration, through the body of the patient, then to the reference electrode used as zero point (REF 2) and back to the common point of the electronic equipment.

This current flow gave rise to potential changes. No current passed through the extra reference electrode, and its potential was therefore unaffected. The recording of the extra reference electrode (REF 1) merely showed the sum of potential changes occurring at the point of contact of the zero reference electrode (REF 2) and in the body of the patient. This was, however, considered negligible since no changes were observed when the extra reference electrode was attached to different points. The potential change of the zero reference electrode was generally within 2 mV.

The potential change observed at the "tooth" input provided valuable information concerning the current-carrying capacities of the metallic restoration, when the above-mentioned potential drop, sometimes appearing in the zero point electrode (REF 2), had been taken into account.

The reference electrodes used were Beckman standard skin electrodes 650944. (Beckman Instrument Inc., Schiller Park, Ill., USA). The small cups around the electrodes were filled with Beckman electrode paste and attached to the skin near the mouth using a two-sided adhesive collar. The electrode element was Ag-AgCl and the paste contained chloride, to give a defined and stable electrode potential. A direct comparison of these commercial electrodes gave a value of -32 ± 5 mV versus a saturated calomel electrode (SCE).

Before taking the measurements for each patient several reference electrodes were compared. Two electrodes with a low potential difference, generally below 2 mV, were then chosen.

The joint registration of potential and polarization of the restorations in the oral cavity allowed for calculation of the current that passed between the contacting restorations. If it is assumed that the current-voltage relationship is linear, the polarization resistance R of the metallic restoration is

$$R = \frac{\Delta E}{I} \quad (1)$$

where I is the applied polarization current and ΔE the resulting potential change (polarization).

In the case of oral metal-metal contacts two metallic restorations can be assumed to have the potentials E_1 and E_2 , as measured versus the reference electrode, and the polarization resistances R_1 and R_2 . At contact between these two metals the galvanic current flowing will be

$$I = \frac{E_1 - E_2}{R_1 + R_2} \quad (2)$$

For twenty-five persons the above described measurements and calculations were made after collection of anamnestic data. Sixteen of the patients formed a group of patients suffering from various kinds of oral discomfort which they themselves attributed to galvanic action in the oral cavity. The remaining nine persons served as a control group and were selected from the staff of the Faculty of Odontology, Malmö. They had no symptoms of the kind mentioned. Measurements and current calculations were performed before and after professional tooth-cleansing. Alginate impressions for study casts were taken together with wax indices in centric occlusion. Finally pantomograms were taken.

II. The same procedures were applied as in Paper I, the only difference being that the time for the introduction of the polarization current was standardized to 0.1 sec and the recorder equipment was changed to a Kompensograph III (Siemens AG, Karlsruhe, FRG).

Part one of this study was performed on two females, one with and another without metallic restorations that could make contact in the oral cavity. The study was performed to study the precision of the measurements of potentials and polarization resistances as well as the precision of the calculation of currents created at metallic contacts.

In part II, current-creation was studied with relation to time in 28 randomly selected students, who were all considered to be in good general and oral health.

III. The same methods and equipments as that described under II were employed in this study.

From the registers of three different branches of the Swedish Social Insurance System 250 persons were selected at random and invited to answer a questionnaire concerning their dental habits, attitudes to dental care and experience

of signs and symptoms of oral galvanism in association with dental care received five years previously.

Among persons who had given answers indicating symptoms of oral galvanism, measurements were taken and calculations made of currents created in metallic contacts. Clinical examination and evaluations of the restorations were also made according to the CDA-system for Quality Evaluation of Dental Care (*California Dental Association 1976*).

The results of the current calculations were compared with those obtained from a control group of persons not suffering from oral symptoms.

Finally, comparisons between the quality of crowns and fixed partial prosthodontics were made between those suffering from certain oral symptoms and a control group.

- IV. From a body of patients referred consecutively to the Departments of Prosthetic Dentistry and Oral Surgery at the School of Dentistry in Malmö, 62 persons, who experienced symptoms suspected to be caused by oral galvanism, underwent measurements of potential and

polarization of their metallic reconstructions in the oral cavity to allow the calculation of the magnitude of the current created at metallic contacts as described above. Further, they were submitted to measurements of their electrical taste thresholds - an inverse measure of the sensitivity for the taste sensation elicited at electrical stimulation on areas where taste buds are present.

The same electrogustometer and method as described in detail by Nilsson (1979) were used.

All results were compared with the findings from corresponding examinations in a control group of persons without any symptoms at all from the oral cavity.

V. From a group of patients referred to the Dental School in Malmö for measurements of potentials and polarizations according to the method described in I and II, three women, aged 50, 55 and 58 were selected. For all of them the maximum current calculated from the results of these measurements were found to be above 25 μ A. Furthermore the selection was also performed on the basis that they complained of certain oral symptoms often associated with oral galvanism.

From the staff of the Dental School in Malmö three women were selected as a matching control group. As far as age, amount and type of oral restorations were concerned one of the members of the control group showed fairly close resemblance to a matching member of the patient group. None of the women in the control group experienced, however, any kind of symptoms or discomforts from the oral cavity, nor had they ever experienced such symptoms associated with oral galvanism.

Further a group of three edentulous women of similar age (50 - 60 years) were selected from the files of patients of the Department of Prosthetic Dentistry at the Dental School in Malmö.

These women, who had all been edentulous for more than 15 years had previously been successfully treated with complete dentures. No visible metal components could be found in their dentures or oral cavities. None of them had ever experienced symptoms associated with oral galvanism.

Finally three girls aged 15 were selected from dental registers over persons who had no metallic restorations in their teeth and had

never had any such restorations.

The potentials and polarizations of the metallic restorations of the three persons in the matching control group were measured according to I and II.

From each of these 12 persons a sample of about 2 ml of whole rest saliva was collected in sterile acid washed tubes. All samples were donated in the morning prior to eating, drinking, smoking and oral hygiene procedures.

According to the method, described in detail by Amos, Bennett, Matousek, Parker, Rothery, Rowe & Sanders (1975), atomic absorption spectrophotometry (Varian AA 6, Varian Techtron Pty Ltd Springvale, Australia) was then performed on the collected samples to determine the saliva concentrations of Ag, Cu, Hg, Sn and Zn.

Briefly, the Zn-contents were determined with flame atomization and the Hg-contents with flameless technique whilst the Ag-, Cu- and Sn-concentrations were determined in a graphite furnace.

RESULTS

I. Besides showing the usefulness of the method for measurements of potentials and polarizations the results of Paper I indicate a wide distribution of the strength of the currents created at metallic contact in the oral cavity. This distribution is illustrated in Fig. 2., which shows the number of tooth-pairs in intermittent contact in the galvanic current interval.

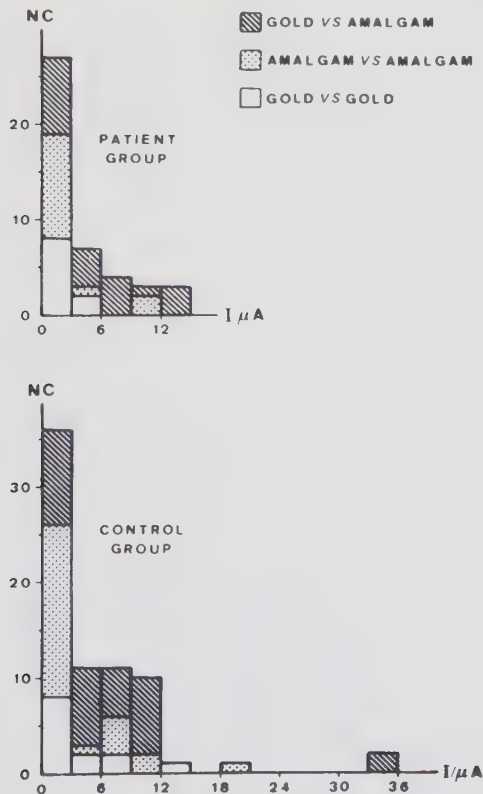


Fig. 2. Number of tooth-pairs in intermittent contact (NC) in the galvanic current interval.

The electrochemical measurements which were carried out within the patient group as well as within the control group revealed no significant differences between the values of potentials measured before and after toothbrushing.

II. Studies on the precision of the method did not reveal any statistically significant differences between currents recorded for a certain metallic contact on the same day and on different days (Fig. 3).

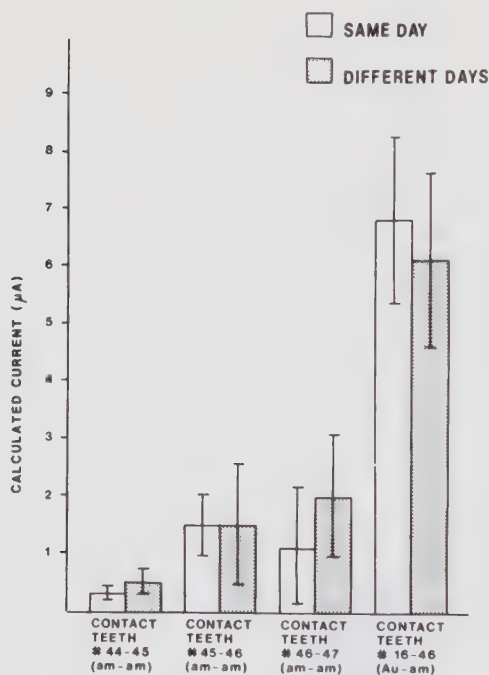


Fig. 3. Calculated mean current (μA) and standard deviation for four different metallic contacts in one test person. Data for these calculations were obtained at 10 single experiments on the same day and at another 10 experiments once a day on different days.

Even if the precision for measurements of potentials and polarization resistances varied somewhat with the extension of the restorations and the conditions in the oral cavity it is obvious that for the currents calculated the precision lies within $1.5 - 2.0 \mu A$.

The results of the time dependence show on average a decrease of current with time over a period of time up to five months. This is illustrated with a regression line in Fig. 4 even if no proof exists for a linear relationship between time and the decline of current magnitudes.



Fig. 4. Calculated mean differences (95 %-confidence-interval) with time of currents (μA) between contacting metallic restorations. Confidence-intervals are only given for days with more than three registrations. (I_1 : current at first visit, I_2 : current at second visit, $\bullet$: mean and $---$: regression line).

III. In the epidemiological study it was not possible to show any statistically significant difference ($p > 0.05$) between persons with certain oral symptoms and those persons without symptoms regarding calculated maximum current created at contact between metallic reconstructions (Fig. 5).

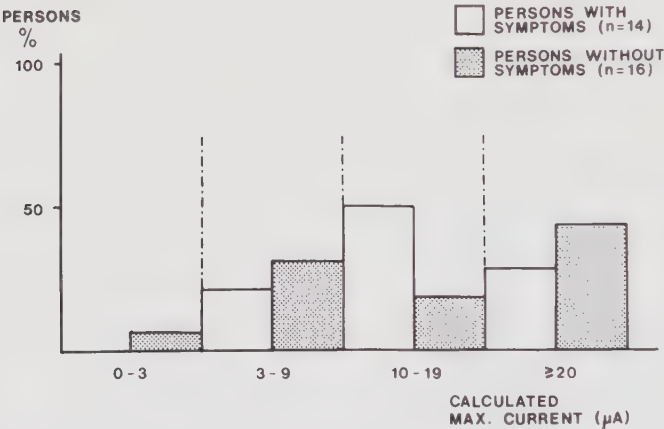


Fig. 5. Distribution of calculated maximum current in persons with and without certain oral symptoms.

Neither were there any statistically significant differences ($p > 0.05$) in the clinical quality of the crowns and fixed partial prosthodontics placed five years previously in the two groups, even if both quality and quantity of the care delivered tended to relate to the amount of oral discomfort (Fig. 6).

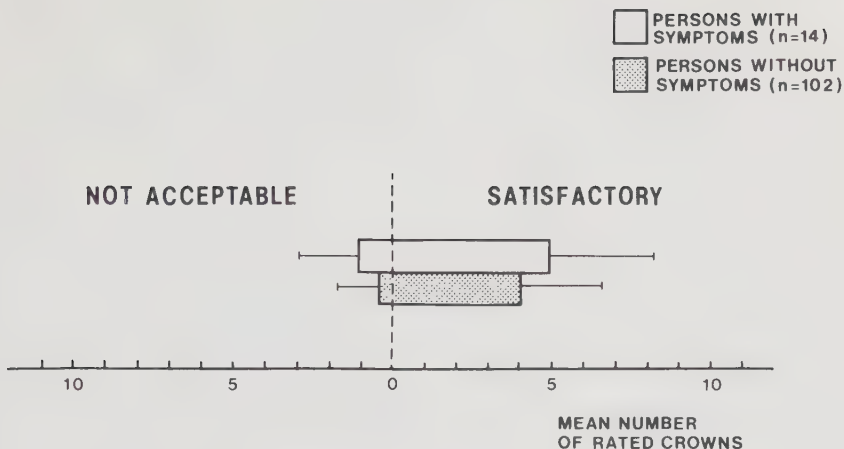


Fig. 6. Distribution of mean not acceptable (with S.D.) and mean satisfactory (with S.D.) crowns in persons with and without certain oral symptoms.

IV. The group of patients with alleged symptoms of oral galvanism were found to have statistically significant different ($0.001 < p < 0.01$) thresholds for electrical taste stimulation on the right side of the tip of the tongue and almost statistically significant different ($0.01 < p < 0.05$) such thresholds on the left side of the tip of the tongue when compared with a group of persons without symptoms.

No statistically significant differences were, however, found when comparing the thresholds on the soft and the hard palate respectively between the two groups.

Furthermore the two groups did not differ statistically significantly with respect to relationship between maximum calculated currents and lowest thresholds for electrical taste (Fig. 7).

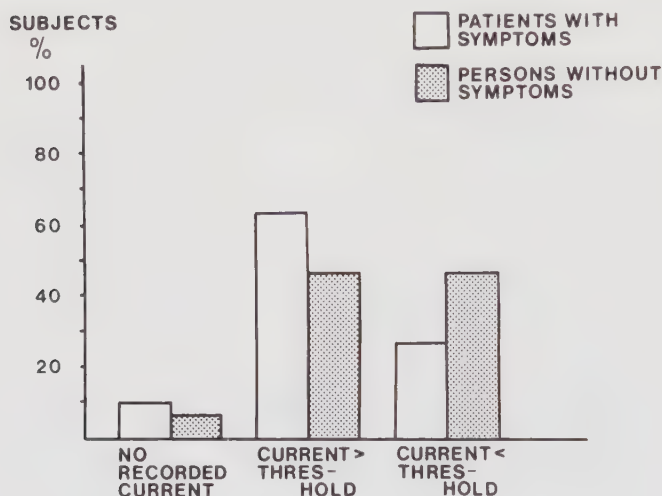


Fig. 7. Distribution of the subjects in a symptom group and a control group by the relationship between maximum calculated intraoral current and the lowest determined threshold for electrical taste.

V. From Figs. 8, 9 and 10 it can be seen, that patients with enhanced oral galvanic action in terms of increased calculated currents at metallic contact between restorative materials, do not exhibit more Ag-, Cu-, or Zn-ions in saliva than persons without metallic reconstructions or patients with metallic reconstructions, but with lower calculated intraorally created currents.

Tin was not detectable and mercury could only be detected in saliva from one of the edentulous females without visible metal components in the oral cavity or the dentures.

The possible cumulative effects of currents created at multiple metallic contacts in the same person were studied at comparisons between subjects with and without certain oral symptoms. No cumulative effects of this kind could, however, be found.

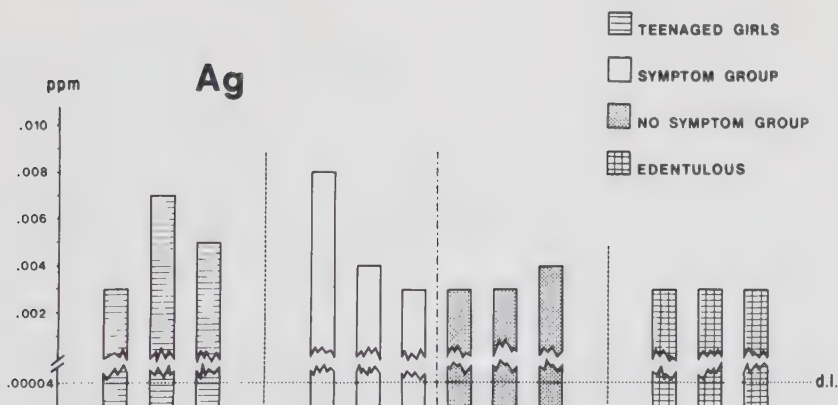


Fig. 8. Silver concentration in whole rest saliva from three female patients with certain oral symptoms, their matched control group without such symptoms, three edentulous females and three teenaged girls without metallic restorations (d.l. = detection limit).



Fig. 9. Copper concentration in whole rest saliva from three female patients with certain oral symptoms, their matched control group without such symptoms, three edentulous females and three teenaged girls without metallic restorations (d.l. = detection limit).

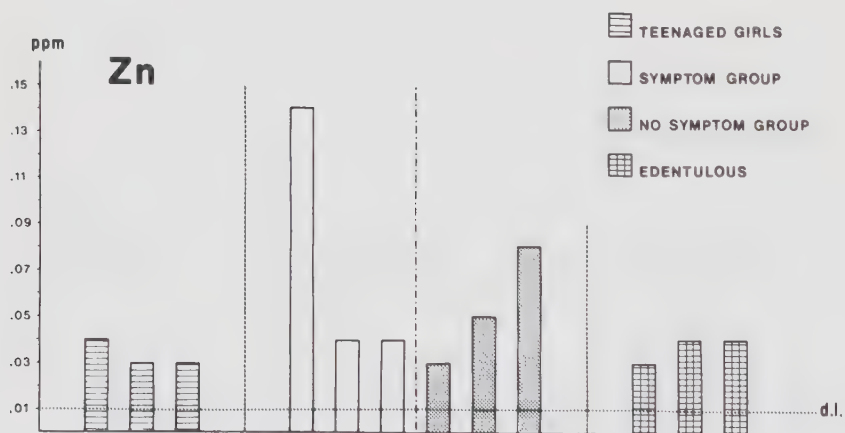


Fig. 10. Zinc concentration in whole rest saliva from three female patients with certain oral symptoms, their matched control group without such symptoms, three edentulous females and three teenaged girls without metallic restorations (d.l. = detection limit).

DISCUSSION

In literature studies on the creation of galvanic currents in the oral cavity have appeared on and off over a period of more than 200 years.

The first report of this phenomenon was made around 1754 by Sulzer, who placed two different metallic objects in the oral cavity, and noted that upon contact between these objects a taste sensation could be perceived. This perception was interpreted as an evidence of electrical activity (*Reinhard & Solomon 1934 and Bujas 1971*).

In the 1870-ies discussions about oral galvanic action and its influence on oral health appeared in association with the introduction of new plastic filling materials such as amalgams - the so-called "New Departure" (*Chase 1879*).

In 1933 reports were made suggesting that "electrical irritation effect produced by some combination of metals used for filling teeth and constructing other dental restorations" was "a possible factor in the production of precancerous and cancerous lesions in the oral cavity" (*Soloman, Reinhard & Goodale 1933*). Simple clinical measurements simultaneously reported did, however, show "no connection between the amount of current measured and the severity of the symptoms".

For a review of the literature before 1933 see Solomon & Reinhard (1933).

The possible connection between oral galvanic activity and biological reactions was again studied and discussed by Schriever & Diamond (1952), who also introduced a special instrument - the so-called condenser-ballistic-galvanometer potential difference measuring meter - in an attempt to avoid polarization effects. Generally speaking the conclusions drawn in this study were in line with those of Solomon, Reinhard & Goodale (1933).

A survey of oral biological phenomena as a consequence of electricity was presented by Mumford (1957).

Before 1960 virtually all attempts to quantify oral galvanic action were based on the measurements of the differences in potentials between oral metallic objects (Solomon & Reinhard 1933, Schriever & Diamond 1952 and Mumford 1957). In a study of the possibilities to electrically stimulate teeth, Mumford and Björn (1962), however, concluded that measurements of oral potential differences can only be "satisfactory provided adequate steps are taken to control the resistance". Similar opinions have been given by Björn (1946) and Marxkors (1965). As no exact measurements have ever been presented on the resistance of any type of oral tissue, the above-mentioned conclusion is of funda-

mental importance at discussions of methods for evaluation of oral electrochemical action.

A number of studies on various types of biological reactions to dental materials started to appear in literature around 1970 (*Gasser 1968, Takahasi 1968, Angmar-Månsson, Omnell & Rud 1969, Frykholm, Frithiof, Fernström, Moberger, Blohm & Björn 1969, Sandrik, Greener & Wragg 1969, Rud & Omnell 1970, Elgart & Higdon 1971, Murphy 1971, Klötzer 1973, Fisher 1974, Natiella 1974, Glantz, Björlin & Sundström 1975, Rost 1976 and Bergman, Bergman & Söremark 1977*).

About the same time a number of studies were reported of experiments of galvanic actions engaging metallic materials (*Fusayama, Katayori & Nomoto 1963, Maschinski 1970, von Fraunhofer & Staheli 1972, Lucas 1973, Arvidson & Johansson 1977 and Holland 1980*). Most of these studies were, however, made in vitro, where it is extremely difficult to create conditions relevant to those existing in the oral cavity where saliva for example plays an important role and may act as a protector of metallic and other surfaces through its potent film forming ability. (*Solomon, Reinhard & Goltz 1938, Shinobu 1955, Baier & Glantz 1978, Jendresen & Glantz 1981*). The studies made in vivo were limited, restricted to determinations of potential differences only, and performed on non-randomized populations.

Bearing this in mind, it was considered of interest

and importance to establish conditions under which it would be possible, with necessary accuracy and precision, to determine such currents as may be created at galvanic action in the oral cavity.

In Paper I measuring methods and equipment are described in detail. Using this equipment a number of experiments were performed (Papers I and II) to study whether or not it could be used at quantifications of different kinds of galvanic action in the oral cavity, and to allow for calculations to be made of the magnitudes of the currents created. The results of these methodological studies show that with the equipment and methods described, it is possible to determine with reasonable precision the magnitudes of currents created at contacts between different metallic restorations in the oral cavity.

An interesting observation made in Paper II was that the precision of the method used is related to the contact relations for the restorations studied. For restorations without functional or proximal contacts, the precision of the clinical measurements were thus found to be many times less than for restorations with such contacts. As galvanic currents of practical importance can hardly be created by restorations without functional or proximal contacts, this is, however, a finding of no relevance in relation to the aims of this study.

A direct relationship exists between the areas of metallic objects and the currents that may be created at contact between these objects (*Gellings 1976*).

In the oral cavity the areas of the metallic restorations which could make contact (Paper II) were, however, not found to vary to such an extent as to give the above mentioned relationship any practical significance.

The approach to calculating currents from measurements of potentials and polarizations has not previously been used at studies of oral galvanic action. No direct comparisons can therefore be made between the final results of this study and those presented in literature. It is, however, a method in harmony with modern ideas in electrochemistry (*Gellings 1976*). Further, when the recorded potential differences (Paper II) were compared with similar type of data previously reported (*Schrieffer & Diamond 1952 and Maschinski 1970*), they were obviously of the same magnitude.

Fundamentally, the results of this study (Paper II) show that as long as the clinical conditions are not altered, there is a decline with time of the current created at metallic contacts in the oral cavity. Consequently, whenever biological reactions of a not too serious magnitude appear due to oral galvanic action, immediate surgical or operative measures are

not justified.

Furthermore, low values for polarization resistance in a restoration can also be taken as a sign of high electrochemical activity. This finding can often be useful in clinical screening of patients with certain oral symptoms.

Studies of frequencies and magnitudes of oral galvanic action in a population with comparatively extensive metallic restorations were reported in Paper III, together with studies of the frequencies of certain objective and subjective oral symptoms possibly associated with oral galvanic action. The outline of this study made it possible to draw general conclusions regarding the above mentioned frequencies and magnitudes in the Swedish population. The results of Paper III show that the creation of currents is a natural consequence to the establishment of metallic contact and that the magnitudes of these currents do not vary systematically between patients with and without the above-mentioned types of oral symptoms. The results of Paper III offer, however, possible explanations at least to some of the subjective symptoms which were thought perhaps to be caused by oral galvanic action.

At the clinical examinations reported in Paper III, no white mucosal lesions or other types of reactions

were noticed except for periodontal inflammatory ones. This gives a prevalence of white mucosal lesions which is lower than that reported by Axell (1976) for a Swedish population. Whether this difference is due to a systematic variation between the populations studied or if it is an examiner effect can not be stated from available data.

The results of Paper I - III suggest that a reason why certain patients experience certain oral symptoms in relation to restorative treatments with metallic appliances, may more often be the physiological behaviour of the patient than the electrochemical conditions created at the treatments.

To test this suggestion a study (Paper IV) was performed, where the relationship could be studied between on one hand the magnitudes of currents created at oral galvanic processes and on the other taste perception thresholds, as determined at electro-gustometry (Nilsson 1979).

Although no statistically significant relationship could be found in Paper IV, it is interesting to note that in a group of patients with certain oral symptoms allegedly caused by oral galvanic action, the average (median) tongue taste thresholds were found to be significantly lower than those recorded in a control group of subjects without symptoms from the oral cavity.

Thus, the results of Paper IV support the opinion that the subjective reactions, which some patients experience due to the electrochemical consequences of treatments with metallic appliances, is mainly a function of biological threshold values.

Theories have been put forward, especially in non-scientific publications, suggesting that through oral galvanic action large amount of ions are leaching out of dental metallic restorations, thereby causing numerous general reactions and diseases of mostly toxic nature. Some suggestions of this kind have also been presented in dental literature (*Gasser 1968 and Till & Wagner 1973*).

These theories were tested in a series of analytical studies of the concentrations of silver, copper, mercury, tin and zinc in saliva samples donated by subjects with and without metallic restorations in their oral cavities, as well as with high and normal magnitudes of the currents created at oral galvanic action (Paper V).

The results of this study unambiguously oppose the validity of the above-mentioned theories, and show that the saliva metal ion concentration is virtually unaffected by the presence in the oral cavity, even of corrosive metallic restorative materials such as dental amalgams.

Paper V provides no information about the possibilities for oral electrochemical processes to influence the metal concentrations of hard and soft oral tissues, thereby causing biological reactions. Rather, studies reported in literature point to the possibility that through the use of metallic restorative dental materials, local increases will appear in the metal ion concentrations of surrounding tissues (*Söremark & Samsahl 1961 and 1962, Söremark, Ingels, Plett & Samsahl 1962, Fredén, Helldén & Milleding 1974 and Möller 1978*). Especially over long periods of time such increased metal ion concentrations may cause hypersensitivity reactions in soft tissues (*Frykholm, Frithiof, Fernström, Moberger, Blohm & Björn 1969 and Fisher 1974*).

CONCLUSIONS

The observations made in this study appear to warrant the following conclusions.

Patients with certain oral symptoms, suspected to be caused by oral galvanism, do not have higher currents, created at metallic contacts between restorative dental materials, than persons without such symptoms.

Patients with certain oral symptoms have lower thresholds for electrical taste stimulation than persons without symptoms.

There is on average no difference between a group of patients with symptoms and a control group regarding the relationship between highest current created at oral metallic contacts and lowest determined threshold for electrical taste.

There are no differences in saliva metal ion concentrations, between persons with and without dental metallic restorations. Neither are there any differences, in this respect, between persons with high and low magnitude of current created.

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Potential and polarization measurements *in vivo* of oral galvanism

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ABSTRACT — Galvanic currents within the oral cavity may have harmful effects on biological tissues. In the present work 16 patients with different kinds of oral and other discomfort and pain which they attributed to oral galvanism were investigated. The potential and polarization of each metal restoration within reach of a platinum probe were measured versus a reference electrode. A recording of these measured values permits a calculation of the currents which may pass between the teeth. A control group of patients with no subjective symptoms of galvanism in the oral cavity was also investigated. The results of the electrochemical measurements showed that conditions for oral galvanism existed within the individuals of the patient group as well as within the control group. One remarkable observation was that the metallic restorations often consisted of different electrically isolated areas with different electrochemical properties. This and other factors influencing oral galvanism are discussed.

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When exposed to conditions present in the oral cavity metallic restorations and appliances are subject to the effects of corrosion processes. Interaction between the metallic material and the environment gives rise to electrochemical reactions. Besides general corrosion, galvanism is spectacular.

Earlier careful selection from a relatively small number of clinically well-tested materials has limited the appearance of oral galvanism. However, the vastly increasing number of metallic materials for dental restorations, and the fact that available specifications do not define acceptable limits of corrosion

resistance, have focused interest on the effects of oral galvanism. Thus the biocompatibility of metallic dental restorative materials has received a great deal of attention in current literature (KAWAHARA, YAMAGAMI & NAKAMURA 1968, TAKAHASHI 1968, BRENDLINGER & TARSITANO 1970, KLÖTZER 1973, BISSADA, IBRAHIM & BARSOUM 1974, LEVANTINE 1974, WOOD 1974).

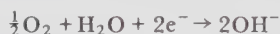
Oral galvanism is possible only when the different electrode materials surrounded by an electrolyte, saliva, are brought into metallic contact. This can be done directly or by a conductor, a silver spoon for example. The electrodes can be

two different restorations made of materials such as a gold alloy and a silver-tin amalgam. In addition, different parts of the same restoration can act as electrodes in the electrochemical cell.

During corrosion metal ions are released by the metal surface according to the following reaction



Simultaneously with this anodic oxidation a cathodic reduction must occur. The main reduction reaction in oral galvanism is the reduction of oxygen



The galvanic current resulting from electrode reactions in the oral cavity may have certain negative effects. The first effect is so-called galvanic pain which can be felt immediately with intermittent contact between different restorations (MUMFORD 1957, CARTER 1965, WATSON & WOLCOTT 1976). If the restorations remain in contact, the galvanic current, because of polarization, will fall to a low and relatively constant level. The second effect is that ion migration into hard and soft oral tissues can cause toxic or allergic reactions due to interaction between corrosion products and biologic tissue (CHARPY 1952, INOVAY & BANOCZY 1961, TÖRNELL 1962, FRYKHOLM, FRITHIOF, FERNSTRÖM, MOBERGER, BLOHM & BJÖRN 1969, ELGART & HIGDON 1971). Finally corrosion damage to the metallic restorative material itself can play a part in affecting the strength and the aesthetic appearance of the restoration (JØRGENSEN 1955, ANGMAR-MÄNSSON, OMNELL & RUD 1968, FRYKHOLM & HEDEGÅRD 1968, RUD & OMNELL 1970).

In the spring of 1976 the authors were contacted by a group of patients suffering from various kinds of oral discomfort which they attributed to galvanic action in

the oral cavity. It was decided that an investigation of these patients would be made with respect to this special kind of trouble. Thus the aim of the present work was to make an attempt to confirm whether oral galvanism could be the probable cause of the discomforts which troubled the patients.

Material and methods

The patient material consisted of 16 individuals, 13 of them living in Malmö or the Malmö region. The remaining three patients were living in Ängelholm, Värnamo and Jönköping respectively. No selection of the patients had been made. Their names were received from the spokesman for the previously mentioned patient group. A control group of nine employees from the Faculty of Odontology, Malmö, with no subjective symptoms of oral galvanism was also investigated for comparison. Distribution of the patients and of the control material in relation to age and sex is presented in Table 1.

On arrival each patient had to complete in writing a brief form with questions regarding the anamnesis. Thereafter the authors interviewed each patient for about 10 min to complete the past history data. Then a brief clinical investigation of the patient was carried

Table 1

Age and sex distribution of patients and of control group. Figures in parentheses refer to control group

Age, years	Male	Female	Total
30-39	1		1
40-49	(1)	3 (4)	3 (5)
50-59	1 (1)	3 (2)	4 (3)
60-69	1	3 (1)	4 (1)
70-79		3	3
> 79		1	1
No. of patients	3 (2)	13 (7)	16 (9)
Average age	51 (49)	62 (50)	60 (50)

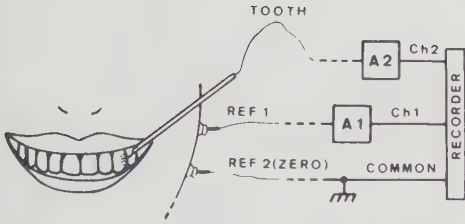


Fig. 1. Principal sketch of experimental set-up. A1, A2 amplifiers.

out and after that the electrochemical measurements were taken. A dental hygienist nurse then carefully brushed and cleaned the patient's teeth as well as any removable prostheses according to standardized practice. No toothpaste was used. After this cleaning of the mouth the electrochemical measurements were immediately repeated. Alginate impressions of both the maxilla and the mandible

were taken together with a wax index in centric occlusion. Finally a pantomogram was taken.

Electrochemical measurements – A sketch of the experimental set-up is shown in Fig. 1. Two reference electrodes were attached to the patient's cheek; one served as a zero point for the voltage measurements and the other had a supervisory function. A platinum tip was used to establish contact with the metallic restorations. The voltages were recorded on a W & W Dual Channel Recorder, series 1200, after passing the electronic devices A1 and A2.

The electronic parts are shown in detail in Fig. 2. A1 and A2 consist of operational amplifiers connected as "voltage followers". The purpose of these followers is to present a very high impedance to the electrodes, to present a low impedance to the recorder and to reproduce faithfully (within 0.1 mV) the signals from the electrodes to the recorder without loading the electrodes. Usually the extra reference electrode (REF 1) is recorded with a sensitivity of 100 mV full scale and the tooth with a sensitivity of 1,000 mV full scale.

A current can be momentarily introduced into the platinum electrode (input marked "tooth"). The current can be either 1 μ A or 10 μ A depending on which button is pressed. The current flows into the metallic restoration, through the body of the patient, to the reference electrode used as zero point (REF 2) and back to the common point of the electronic equipment.

The current flow gives rise to potential changes. The extra reference electrode does not pass current and its potential is unaffected. The recording of the extra reference electrode (REF 1) shows the sum of potential changes occurring at the zero reference electrode (REF 2) and in the body of the patient. The latter is negligible since no changes were observed when the extra reference electrode was attached to different points. The potential change of the zero reference electrode is usually within 2 mV.

The potential change observed at the "tooth" input provides valuable information concerning current-carrying capacities of the metallic restoration. The value measured has to be corrected for the potential drop in REF 2 but the correction is very rarely of importance.

The reference electrodes were Beckman standard skin electrodes 650944. The small cups were filled with Beckman electrode paste and attached to the skin near the mouth using

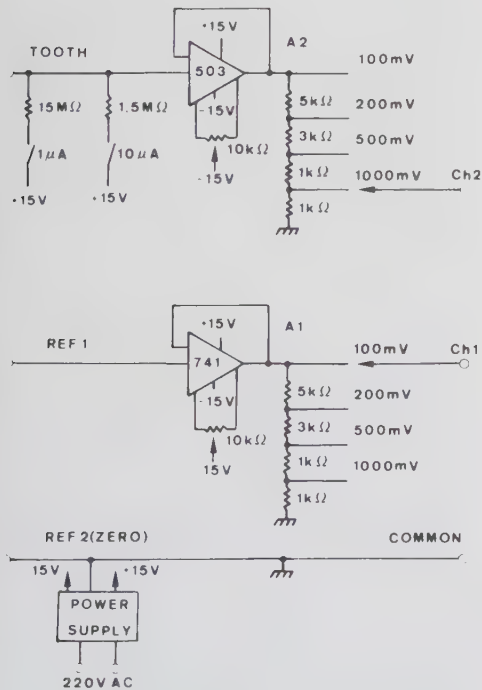


Fig. 2. Schematic diagram of electronic parts. Operational amplifiers 503=Analog Devices 503 J., input current = 1 nA. 741=741 CN, input current = 100 nA.

a two-sided adhesive collar. The electrode element was Ag-AgCl and the paste contained chloride, thus giving a defined and stable electrode potential. A direct comparison of these commercial reference electrodes gave a value of -32 ± 5 mV versus SCE (saturated calomel electrode).

Before taking the measurements for each patient at least four reference electrodes were compared. Two electrodes were chosen with a low potential difference, commonly below 2 mV. The zero reference electrode was chosen for a low potential drop at current flow. During the measurements the recording of the extra reference electrode served as a supervision of the zero reference electrode.

Results

Primary electrical recordings – A small extract of a recording is shown in Fig. 3. This recording demonstrates several items: (1) The necessity of using a recorder to obtain meaningful results, even if a stable reference electrode is used. Attempts to measure directly between two metallic restorations would be virtually impossible. (2) The potential difference between the two reference electrodes is within 1 mV. The polarization current only polarizes the zero reference electrode negligibly, within 1 mV. (3) The recording of tooth 26 shows that the main part of the restoration has a well-defined potential of -100 mV, with a polarization of 5 mV (occasion d), but small positive deviations are observed as the platinum probe is moved over the surface of the restoration. (4) The recording of tooth 25* demonstrates the presence of several surfaces with different potentials and with different polarizations: in the last part of

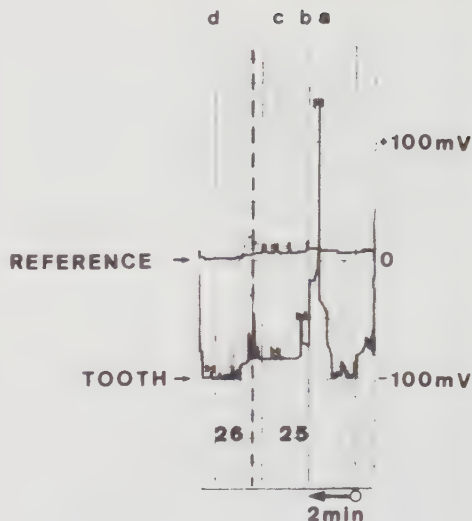


Fig. 3. Primary recording of two adjacent teeth, 25 and 26. Horizontal scale: 2 min/cm, increasing time to the left. Vertical scale: potential recording, 1,000 mV full scale for recording of teeth. Control line is recording of supervisory reference electrode, sensitivity 100 mV full scale, same zero point. The sign denotes passage of a momentary polarizing current of $1 \mu\text{A}$, at occasions a, b, c and d. Time scale of recording of reference electrode is situated 0.2 min later than the recording of the teeth.

the experiments with tooth 25 the probe is in contact with an electrically smooth surface with potential -83 mV and with a very small polarization (occasion c); on occasion b, the probe is in contact with a surface with a potential of -70 mV and with a polarization of 15 mV; on occasion a, the probe is in contact with a surface with a potential of about -30 mV and with a polarization of 160 mV; before occasion a, the presence of a surface with a potential of -98 mV is indicated.

Different electrochemical surfaces on one restoration – It was found that these results had a general validity. Very often the metallic restorations consisted of several surfaces with different potentials and

* After the two-digit system of designating teeth, recommended by F.D.I., 25 is the maxillary left second premolar and 26 the maxillary left first molar.

polarizations. This is perhaps not so surprising when amalgam restorations are studied, where surfaces of dissimilar appearances are easily visible, but the effect was also found on bright gold constructions and even on seemingly homogeneous plates and bars of cobalt-chromium.

It should be pointed out that two metals in metallic contact should exhibit the same electrode potential when they are immersed in a solution. In those cases where the head of a screw-post was visible at the occlusal surface of an amalgam restoration the screw-post alloy, which was mainly brass, had the same or almost the same potential as the surrounding amalgam.

This was confirmed by *in vitro* experiments with the same experimental set-up as used in the *in vivo* tooth restoration measurements. *In vitro* different metallic restorations in metallic contact also had the same polarizations.

Calculations of the galvanic current — A schematic representation of the results of the electrochemical measurements is given in Fig. 4. Such diagrams were made for all the individuals within the patient group and the control group.

The contemporaneous registration of potential and polarization of the metal restorations in the oral cavity admitted a calculation of the current passing between two restorations in occlusal contact. If it is assumed that the current-voltage relationship is linear, the polarization resistance R of the metallic restoration is simply

$$R = \frac{\Delta E}{I} \quad (1)$$

where I is the applied polarization current and ΔE is the resulting potential change (polarization). Now the case of a metal-metal contact in the mouth can be studied. Suppose we have two metallic

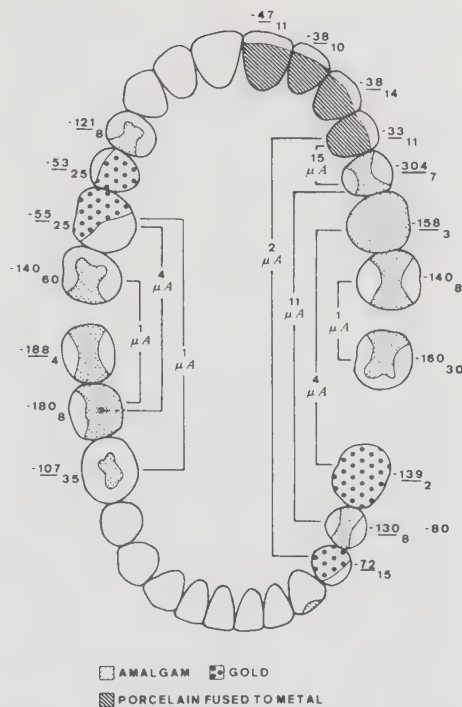


Fig. 4. Schematic picture illustrating results of electrochemical measurements for patient No. 5. Figures outside the row of teeth denote potential values in mV measured at restoration in question; lower figures denote corresponding polarizations measured in mV (polarization current $1 \mu A$). Underlining of figures implies that data are quite reliable. Figures within the row of teeth denote calculated currents passing between teeth in occlusal contact. x at 47 denotes the visible head of a screwpost.

restorations with potentials E_1 and E_2 , measured versus the reference electrode, and with polarization resistances R_1 and R_2 . If these two metals are brought into contact, the galvanic current flowing will be

$$I = \frac{E_1 - E_2}{R_1 + R_2} \quad (2)$$

It should be noted that the current-voltage relationship is not linear for

polarizations larger than about 10 mV (VETTER 1967). Equations (1) and (2) are to be regarded as a first approximation but may be used for diagnostic purposes.

The contacts in centric occlusion were studied clinically and on plaster models of the jaws. These contacts are illustrated as lines in Fig. 4. For each possible contact the galvanic current was calculated according to equation (2) and introduced in Fig. 4.

The number of teeth with various metallic restorations in occlusal contact as a function of the current passing between the teeth in question is illustrated in the diagrams of Fig. 5 for the patient group and the control group respectively. As can be seen from the diagrams there are more contacts within the control group than within the patient group. This is due to the fact that the control group, which is of lower average age than the patient group, has more remaining teeth. From the diagrams can also be seen that the magnitude of the currents passing through the teeth of the control group is greater than for those of the patient group.

Remaining results – Some data concerning the patient group are collected in Table 2. It is obvious from the past history information that the main type of oral discomfort seems to be different kinds of pain in the tongue, especially burning and smarting pains. Changes in salivation, in most cases meaning a decreased salivation, is another frequent symptom together with a metallic taste. Further information of interest is that several of the patients used sleeping pills and five of them sedatives (Nos. 7, 8, 9, 11, 14). In many cases the patients were not able to name these or other types of medicaments used. One of the patients (No. 5) had been tested with different kinds of allergens. It was found that the patient in question was

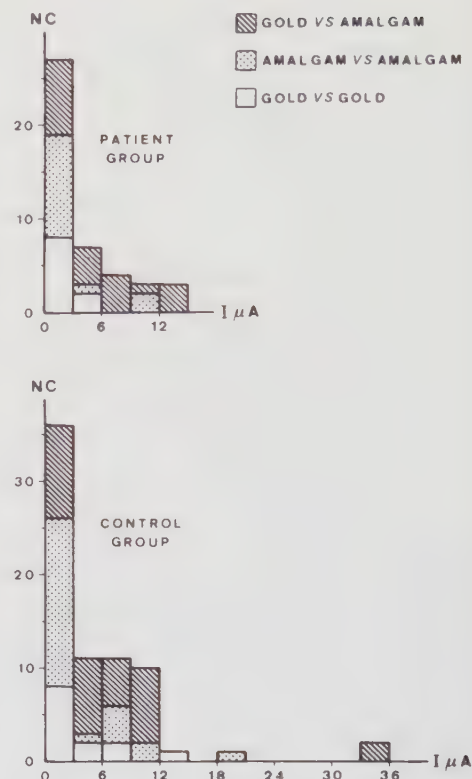


Fig. 5. Number of tooth-pairs in intermittent occlusal contact (NC) in the galvanic current interval.

allergic to penicillin and gold-salt. Another patient (No. 8) was troubled now and then with vesicles on the skin of the hands and ears in connection with the use of jewelry. This patient had also been tested for allergies but showed negative reactions for gold and acrylics. In some cases the patients associated the début of their troubles with dental measures such as for example the insertion of a gold bridge. Three of the patients (Nos. 4, 7, 16) had suffered from their pains for 10–15 years, the remainder for periods of 1–4 years.

The brief dental investigation revealed nothing unusual in the oral status of the

patients with regard to their ages and the heterogeneous combination of the individuals of the group. The metal restorative materials present in the oral cavity were registered clinically and by use of pantomograms. The degree of tarnish on the visible metallic materials varied but was in no case extremely severe. No common trend was found with regard to this effect. In Table 2 some observations are given concerning mucous membranes with special respect to the appearance of the tongue. However, these observations of the tongue scarcely reveal any remarkable conditions which could be directly related to the subjective symptoms described by the patients.

The electrochemical measurements which were carried out within the patient group as well as within the control group revealed no significant differences as regards the potential values measured before and after toothbrushing.

Discussion

Different surfaces on one restoration – The presence of different, electrically isolated surfaces on the restorations was demonstrated in this work. The different polarization of these surfaces is decisive proof of electrically insulating layers between different surfaces. This means that the surfaces have individual contact with the mouth fluid and have only limited mutual contact. From the point of view of galvanic currents this is advantageous. When two metallic restorations are brought in contact, only a minor part of the restoration will give rise to galvanic current.

Different types of restorations – As can be seen from Table 2, 13 of the patients had gold restorations in their oral cavities. The constructions were made of several

different gold alloys including those used for the ceramic-metal technique. Dental gold alloys are far from homogeneous in their structure and composition. Segregation of alloy elements resulting in a cored and dendritic structure together with extraneous materials present in the form of inclusions frequently occur (e.g. SÖREMARK, FREEDMAN, GOLDIN & GETTLEMAN 1966, YLI-URPO 1975, BERGMAN 1976). The very presence of a solder alloy also contributes to the inhomogeneity of any dental restoration because the composition of the solder is different from that of the cast alloy. These dissimilarities between and within the gold restorations are one of the conditions for electrochemical corrosion.

As regards dental amalgam restorations corrosion is considered to be one of the major causes of failure. The structure of set amalgam is not homogeneous as different phases are present. Each of these phases has a different corrosion potential and electrolytic action between dissimilar portions of the fillings may occur. It has been pointed out by JÖRGENSEN & SAITO (1970) and JÖRGENSEN (1972) and by a number of other investigators that the most corrodible phase is γ_2 or the tin-mercury phase. After packing and carving the surface layer of an amalgam filling is likely to contain more of the γ_2 phase than the body of the filling (FRAUNHOFER 1975). This is the probable explanation for the fact that the single recent amalgam filling in the experimental material had the lowest potential value, -520 mV.

Toxic and allergic reactions – Various kinds of corrosion products which are released from metallic dental restorations can penetrate into hard and soft oral tissues (BERGENHOLTZ, HEDEGÅRD & SÖREMARK 1965, SÖREMARK, WING, OLSSON & GOLDIN 1968) and, via the saliva, reach the gastrointestinal tract. The remains of

Table 2

Main types of oral discomfort and alloys present at the time of the examination. A, amalgam. G, gold. Co-Cr, cobalt-chromium. SS, stainless steel. Sp, screw-post alloy

Patient No.	Taste	Saliva (+, increase -, decrease)	Subjective symptoms		Alloys present in oral cavity	General appearance of mucous membranes of tongue, alveolar ridges and palate
			Other types of oral discomfort			
1	Bitter	-	Burning tongue left side, sometimes sores on tongue		A, G, Sp	Redness of tongue front, left side Mucous membranes dry and sensitive
2			Smarting tongue, continuously but varying in strength, tongue some- times swollen		A, Sp	Tongue edges smooth, redness of tongue tip
3		+	Burning tongue, ceases when the removable partial prostheses is taken out		A, Co-Cr	Tongue edges smooth and reddish
4		-	Smarting and burning pain in whole mouth, "tongue like sandpaper"		A, Co-Cr, SS	Papillas at tongue back somewhat raised. Mucous membranes dry and sensitive
5	Metallic (lead)	-	Burning tongue and burning pain in mucous membranes in throat (and nose)		A, G, Sp	Nothing noteworthy
6	"Battery taste"	+	Dry mouth, although salivation is felt to be heavy		A, G, Co-Cr, Sp	Rather fissured tongue
7	Metallic		General soreness and pain in gum and jaws, continuously		A, G, Co-Cr	Mucous patches on left mandible

(Table 2 continued)

8	+	Pain and itching in the front of palate	A, G	In the palate at 21, 22 small elevated flap of mucosa (previous fistula)
9		Burning and smarting pain in the mouth, vocal chords irritated	G, Co-Cr	Rich brownish-yellow covering on tongue
10	-	Smarting pain in the mouth, burning tongue especially in the region of bridge in maxillary front	A, G, Sp	Rather fissurated tongue, redness of tongue tip and edges
11	-	Smarting throat and mouth, now and then mucous patches at the "gum" of both jaws	A, G, Sp	Nothing noteworthy
12	-	Burning tongue, palate and throat, tongue sometimes swollen and felt "like sandpaper"	A, G, Sp	Enlarged papillas of tongue back
13	-	Chronic inflammation of tongue, throat and salivary glands. Every 3rd or 5th day "acid precipitations" in the mouth	A, G	Smooth edges of tongue. Mucous membranes very sensitive and dry in the whole mouth
14	-	Diffuse pain in front part of mandible	A, G, Sp	Redness of tongue tip right side
15	-	Burning tongue, dryness, sporadic sores on tongue	A, G	Relatively thick grayish-white covering on tongue back
16	-	Mucous membranes of throat (and nose) irritated. General smarting and burning pain. Sores of palate and alveolar ridges now and then. Right front part of tongue strong burning	G	Mucous membranes dry and sensitive

these corrosion products which are not excreted are then further distributed to various parts of the human organism, sometimes reaching specific target organs where accumulation occurs.

Elements such as cadmium and to some extent also beryllium are examples of highly toxic elements which are integral parts of certain dental alloys. As shown in a previous *in vitro* study (BERGMAN & GINSTRUP 1975) cadmium, copper and zinc under certain given circumstances can be dissolved from dental gold solder alloys. Hypersensitivity reactions, such as allergic contact stomatitis and generalized dermatitis in nickel-sensitive patients with different kinds of dental prostheses, have been described in the literature (FOUSSEREAU & LAUGIER 1966, FISHER 1974). As is seen from Table 2 there were five patients (Nos. 3, 4, 6, 7, 9) with cobalt-chromium frameworks in their removable prostheses. All these patients related their main oral discomforts directly to the installation and use of the prostheses. However, the important question regarding types of cobalt-chromium alloys and contents of nickel could not be clarified without an analysis of each alloy material.

In the present study the main purpose was to find out whether any conditions for oral galvanism existed among the patients. It has been shown that potential differences existed between and within various metal restorative materials. The resulting galvanic currents were of a magnitude of 1–36 μ A, and some of the highest values within this range were found in the control group. As for the patients with galvanic currents of 5 μ A or more through the teeth it was judged that these currents *could* be one possible explanation for their oral discomforts. Information regarding the results of the electrochemical measurements were sent

to the dentists of the patients in question together with some simple suggestions regarding suitable measures to keep galvanism under control.

The measuring method and equipment described in the present work can thus be used to find out whether different kinds of galvanic action exist in the oral cavity and also permit a calculation of the magnitude of existing currents. The question whether this galvanism causes pain and discomfort to a particular patient is, however, far more complex. With regard to the patient material studied in the present work it seems to be mainly a function of biological threshold values.

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ON INTRAORAL POTENTIAL- AND POLARIZATION-MEASUREMENTS
OF METALLIC RESTORATIONS

A methodological and time dependent clinical study

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Running head: Potential and Polarization Measurements

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On intraoral potential- and polarization-measurements of metallic restorations. A methodological and time dependent clinical study. Acta Odontol. Scand.

A study was conducted to scrutinize the precision of a method for in vivo potential and polarization measurements. The variation with time of the magnitude of currents created at contacts between metallic dental restorations of varying age was also studied.

The precision found indicates that the method allows for comparatively precise measurements of potentials to be taken. Studies of performed measurements of polarizations show that the precision of these measurements varies somewhat with contact conditions and the areas of restorations examined.

The precision of the currents calculated was found sufficient for precise enough calculation to be made of the magnitude of currents created in the oral cavity.

The study also shows a decrease with time of the magnitude of currents created at contacts between metallic dental restorations of varying age.

Key words: in vivo; electrochemistry; methodology

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Several methods for studies of the electrochemical characteristics of metallic dental materials have been described in literature (e.g. 2,3,5,8,9,10,14,16). The majority of these methods were designed for use in vitro, and it was not until Bergman, Ginstrup & Nilner (2) presented an instrument and a method for in vivo-use that accurate enough clinical measurements could be taken relevant to assess intraoral electrochemical activities.

Evaluation of any set of recordings has to be judged in relation to the precision of the method used. As no systematic studies have been presented on the precision of the method for clinical measurements of potentials and polarizations described by Bergman et al (2), it was considered worthwhile to perform such a study (Aim of Part I).

Further, as single observations of high intraoral currents - galvanic shocks - have been reported at metallic contacts engaging newly made restorations (2,12,13,17), it was also considered worth performing a study of the variations with time of the magnitudes of currents created at contacts between metallic dental restorations of varying age (Aim of Part II).

MATERIALS AND METHODS

Part I:

Two females, age 22 and 49 years, were used as test persons in Part I of this study. Both considered themselves to be in good general health and were found to be in good oral health upon clinical examination. On the younger test person, who did not make metallic contacts between any of her 10 amalgam restorations, potential- and polarization measurements were made at ten separate occasions during a 4 hour time period. In the following these restorations will be referred to by Roman numerals I - X. The only alteration between the method used in this study and that described by Bergman et al (2) was that the

time for the exposure to the polarization current was standardized to 0.1 sec. On this test person additional measurements were also taken four months and one week before the repeated one-day measurements.

On the older test person, who made several functional as well as proximal contacts between extensive amalgam and gold alloy restorations, one gold alloy unit (tooth no 16), serving as pontic in a fixed bridge, and four extensive amalgam restorations (teeth nos 47, 46, 45 and 44) were selected for the study. In Figs 1 and 2 these restorations will be referred to by the Roman numerals V, IV, III, II and I respectively. On these restorations, 10 experiments of the above mentioned type, were performed during a total time period of 8 hours. On this test person additional experiments were also performed as one experiment per day or as one experiment every other day during a subsequent eighteen-day period.

Part II:

For this study, totally 30 persons were randomly selected as test persons out of the student body of the School of Dentistry at the University of Lund, Malmö, Sweden. Two of the selected students had terminated their studies at the school and therefore, 28 persons, 21 males and 7 females, took part as test persons.

The mean age of the selected group was 25.4 years $\pm$ 3.2 years (S.D.). Upon clinical oral examinations all members of the group were found to be in good oral health except for minor technical and aesthetic defects on a few restorations in eight of the selected persons. All considered themselves to be in good general health.

On all these test persons, potentials and polarizations were measured for every metallic restoration at two different experimental visits. The method used was the one given in Part I.

The time elapsing between the visits varied between 0 and 152 days with a mean of 64 days. For the eight test persons mentioned above certain metallic restorations were either inserted or under replacement between the first and second visit.

Clinical records, impressions and indices were taken of all test persons. Based on studies of these records and the produced study casts, identifications were made of anatomical and functional metallic contacts.

RESULTS

Part I:

The results of the measurements performed on the two test persons with and without intraoral metallic contacts are presented in Figs 1 and 2, where Fig 1 shows the mean surface mixed potentials (E) with respective standard deviations for the reconstructions of the two test persons. Fig 2 shows the corresponding mean polarization resistances (R) calculated according to the equation:

$$R = \frac{\Delta E}{I_0} \quad (1)$$

where ΔE is the polarization created by the polarization current I_0 to which the metallic reconstruction was exposed for 0.1 sec.

Using these data, for the test person with intraoral metallic restorative contacts, the current at each of the four studied contacts were calculated according to the equation:

$$I = \frac{E_1 - E_2}{R_1 + R_2} \quad (2)$$

where I denotes the generated current, E_1 and E_2 the mixed potentials measured at the surface of each of the two contacting metallic restorations, and R_1 and

R_2 their respective polarization resistances. The results are given in Fig. 3.

A t-test of the data given in Fig. 3 did not show the presence of statistically significant differences between the currents recorded for a certain metallic contact on the same day and different days.

For the test person without intraoral metallic contacts, currents could for obvious reasons not be calculated. As this test person had, however, amalgam restorations of two distinctively different types - 7 single surface restorations (classes I or V according to Black's classification) and 3 two-surface restorations (class II according to Black's classification) - the mean surface mixed potentials and polarizations were measured for these two types of restorations (Table I). In Figs. 1 and 2, where these restorations are referred to by Roman numerals, nos. V, VI and IX denote the class II-restorations.

The Mann Whitney U-test (15) which was carried out on the data given in Table I did not show the presence of statistically significant differences between the surface mixed potentials of the two types of restorations ($p > 0.05$). Between their respective polarization resistances, however, statistically significant differences were found ($0.05 > p > 0.01$).

Part II:

For the group of 28 students, the calculated mean intraoral currents at the first experimental visit were $3.48 \mu A \pm 5.60 \mu A$ for amalgam/amalgam contacts ($n = 130$), $1.28 \mu A \pm 1.29 \mu A$ for gold/gold contacts ($n = 13$) and $6.06 \mu A \pm 3.99 \mu A$ for gold/amalgam contacts ($n = 6$). At the second visits for corresponding currents were found to be $1.84 \mu A \pm 3.06 \mu A$ ($n = 131$) for amalgam/amalgam contacts, $0.77 \mu A \pm 0.61 \mu A$ ($n = 14$) for gold/gold contacts and $4.80 \mu A \pm 4.07 \mu A$ ($n = 6$) for gold/amalgam contacts. The mean current for all restorative contacts was $3.39 \mu A \pm 5.33 \mu A$ ($n = 149$) at the first

visit and $1.85 \mu\text{A} \pm 2.97 \mu\text{A}$ ($n = 151$) at the second.

An analysis of variance of these data showed that at the first experimental visit there were no statistically significant differences ($p > 0.05$) between the experimental data obtained for the studied combinations of restorative materials. Between the data obtained at the second visit, however, significant such differences ($0.05 > p > 0.01$) were observed.

Further, paired t-tests on the data for the first and the second visit showed the presence of highly statistically significant variations ($p < 0.001$) between the currents calculated for the same contacting pairs. When these tests were split for the existing material combinations it was evident that the observed statistically significant variations originated from the data for the amalgam/amalgam contacts ($p < 0.001$), whilst those obtained for gold/gold and gold/amalgam contacts did not show any such significant variations ($p > 0.05$).

In order to study the directions of observed current variations, for all studied current sources (including two contacts between amalgam and the metal of crowns with fused porcelain) a graphic representation was made of the magnitudes and directions of the recorded differences between the second and the first experimental visits versus time (Fig. 4).

The slope of the regression line ($r = -0.0311$) in Fig. 4 reveals that in a population of dentate persons with a high interest in and awareness of their dental state and also receiving all types of required dental care the magnitude of the currents between contacting metallic restorations decreases with time.

Corresponding graphic representations were plotted for sub-groups with respect to sex and restorative treatment between visits. The only other type of variation than that given in Fig. 4 was noted for the group of test persons who had undergone restorative treatment between visits. For currents calculated in

this group a slight increase could be observed.

DISCUSSION

One of the aims of this study was to define the precision of a clinical method for measurements of potentials and polarizations of intraoral metallic restorations.

These potentials (E) and determined polarization resistances (R) were then used at calculations of the magnitude of intraoral currents (I).

Because of the relationship given in equation (2) the precisions of measurements of potentials and polarization resistences determine the precision at the calculations of the magnitude of the currents generated.

The first part of this study was performed on two test persons with such intraoral conditions that it became possible to determine the precision of the measuring method used with regard to time and contact relations between restorations. The study of the latter variable was made possible as the restorations of one but not the other of the test persons made neither proximal nor intermaxillary contacts.

When the precision was examined for the two types of metallic contacts (amalgam/amalgam and gold/amalgam) under study, no systematic differences could be noted. It was, however, noted that out of the four contacts examined the one made by dissimilar metal alloys had the highest current. This is reasonable bearing in mind the different inherent electrochemical characteristics of the contacting alloys (4). This observation was also made when changes in the currents over a period of time were studied for the various material combinations found in the test persons of Part II of this study.

In this context it should be noted that the comparatively rapid current shifts with time, which were observed in Part II for amalgam/amalgam contacts,

only indicate the relatively dynamic electrochemical nature of dental amalgams as compared with dental gold alloys (1). These data do not, however, offer any information about possible differences in the mean magnitudes of currents at contact between different materials.

Due to the fact that amalgam is the anodic component of virtually any amalgam/gold alloy cell, there is at least a theoretical possibility to decrease the gap in potential due to sorbtion of amalgam components on cathodic gold alloy surfaces. In order to minimize the risks for generation of clinically significant currents between dental metallic restorations, those in contact should therefore as long as possible be made of the same or similar type of material. Whenever for example an amalgam restoration has to be created in contact with an existing gold alloy restoration, the relatively electrochemically inert non γ_2 -types of alloy should therefore be favoured over conventional ones (6).

Further, and as a consequence of the above mentioned facts, extremely unfavourable conditions may be created at contacts between small anodic materials and large cathodic ones. Therefore, small amalgam restorations should also be avoided in contact with the metal components of extensive bridge reconstructions in dental gold alloys (6).

As shown in Fig. 1, the precision of measurements of surface mixed potentials was found to be comparatively independent of contact conditions.

The precision at determination of polarization resistances increased at studies of relatively extensive restorations with possible contacts with other metallic restorations (Fig. 2). Small restorations without such metallic contacts, i.e. without systematic possibilities for short-circuiting, were on the other hand responsible for the overall poorer precision obtained at repeated clinical

experiments. For such restorations it should be borne in mind that their high polarization resistances, probably due to their small areas and low amounts of structural imperfections (7), support the assumption that a linear relationship between the magnitude of the polarization current density and the shift caused in surface potential can only be approximated within narrow ranges (2).

The results given in Fig. 2 and Table 1 further indicate that when the size was increased for isolated restorations, the precision was also increased at determination of their polarization resistances. Nevertheless, for those restorations the level of precision was several times below that found for restorations with functional or proximal contacts. Low values for polarization resistance in a restoration may be a sign of high electrochemical activity. This can often be useful in clinical screening of patients with oral symptoms.

The occurrence of short-circuiting is therefore obviously a major conditioning factor, probably through striving for a common surface mixed potential for the contacting restorations. Here it should be noted that, when this is not successful, for example due to extensive inhomogenities or excessive wear, conditions may be created that will cause discomfort as well as pain (2,11,14).

Studies of the time dependence of intraoral currents show that their magnitude decrease over a period of up to five months. This is a quite reasonable finding bearing in mind the general corrosion resistance of the restorative materials studied and the fact that no exceptional volumetric differences existed between them. It is not possible to determine exactly how long the decrease will go on. Theoretically it should, however, continue until the two contacting metallic objects have obtained the same electrochemically characteristics i.e. until there is no electromotive force to generate currents

between them. As the magnitude of the current approaches zero, however, the rate of the electrochemical homogenisation probably declines. As a result and due to changes in oral conditions, which may further affect different metallic restorations in different ways, it is from both practical and clinical points of view likely that with methods and instruments of a high enough degree of precision, currents will always be found between contacting oral metallic restorations.

In fig. 4 the distribution of the recordings is complex and difficult to interpret. For matters of simplicity a straight line was, however, drawn. The interesting feature in this figure is the continuous decrease found for the strengths of the currents studied.

In conclusion, the results of this study show, that the instrument and the method presented by Bergman et al (2) is suitable for studies of intraoral current generation, and that there is a decrease with time of the magnitudes of currents created at contacts between metallic dental restorations of varying age.

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Table 1

Mean surface mixed potentials (mean $\pm$ S.D.) versus a Ag/AgCl-reference electrode and mean polarization resistances (mean $\pm$ S.D.) for single-surface (classes I or V) and two-surface (class II) amalgam restorations in the same person. (n=10 for every restoration).

Type of restoration	N	Mean surface mixed potential (mV)	Mean polarization resistance (k Ω)
Single-surface (I and V)	7	- 169.0 $\pm$ 36.31	102.3 $\pm$ 81.43
Two-surface (II)	3	- 196.0 $\pm$ 7.85	9.7 $\pm$ 2.55

LEGENDS

Fig. 1 Mean surface mixed potentials (mV) and standard deviations of these means obtained at repeated (same day and different days) measurements of potentials (versus a Ag/AgCl-reference electrode) of five restorations on one test person (A) with and of ten restorations on another test person (B) without intraoral metallic restorative contacts. (Restorations referred to by Roman numerals - see text. $n=10$ for all restorations except for person B at different days where $n=3$).

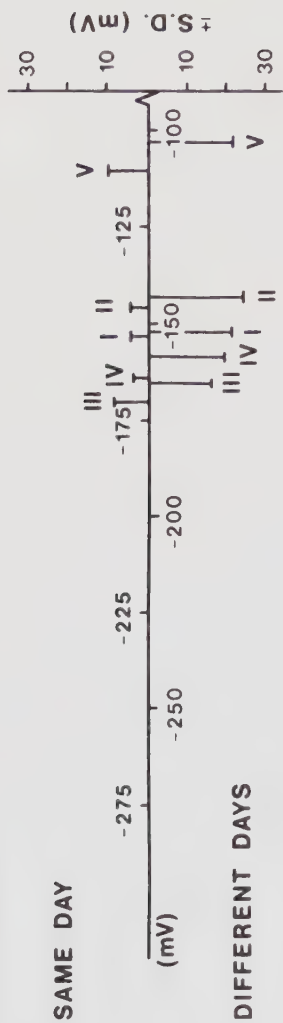
Fig. 2 Mean polarization resistances ($k\Omega$) and standard deviations of these means as calculated from repeated (same day and different days) measurements of five restorations on one test person (A) with, and of ten restorations on another test person (B) without intraoral metallic restorative contacts. (Restorations referred to by Roman numerals - see text. $n=10$ for all restorations except for test person B at different days where $n=3$). Note the different magnifications in fig.

Fig. 3 Calculated mean currents (μA) and standard deviations for four different metallic contacts in one test person. Data for these calculations were obtained at 10 single experiments on the same day and at another 10 experiments performed once a day on different days.

Fig. 4 Calculated mean differences (95%-confidence-interval) with time of currents (μA) between contacting metallic restorations. Confidence-interval is only given for days with more than three registrations.

(I_1 : current at first visit, I_2 : current at second visit, $\bullet$: mean and $---$: regression line).

TEST PERSON A



TEST PERSON B

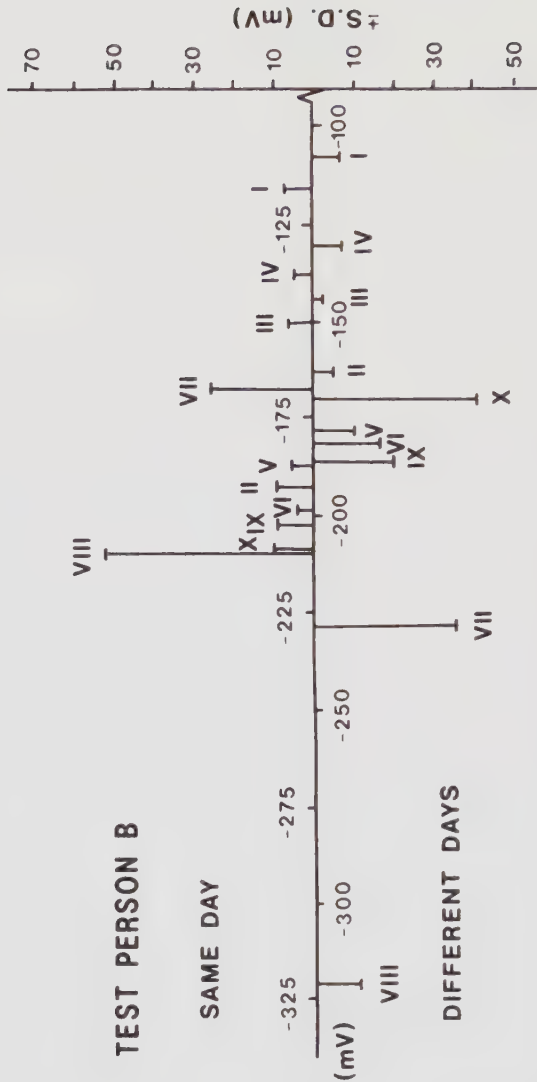


Fig. 1.

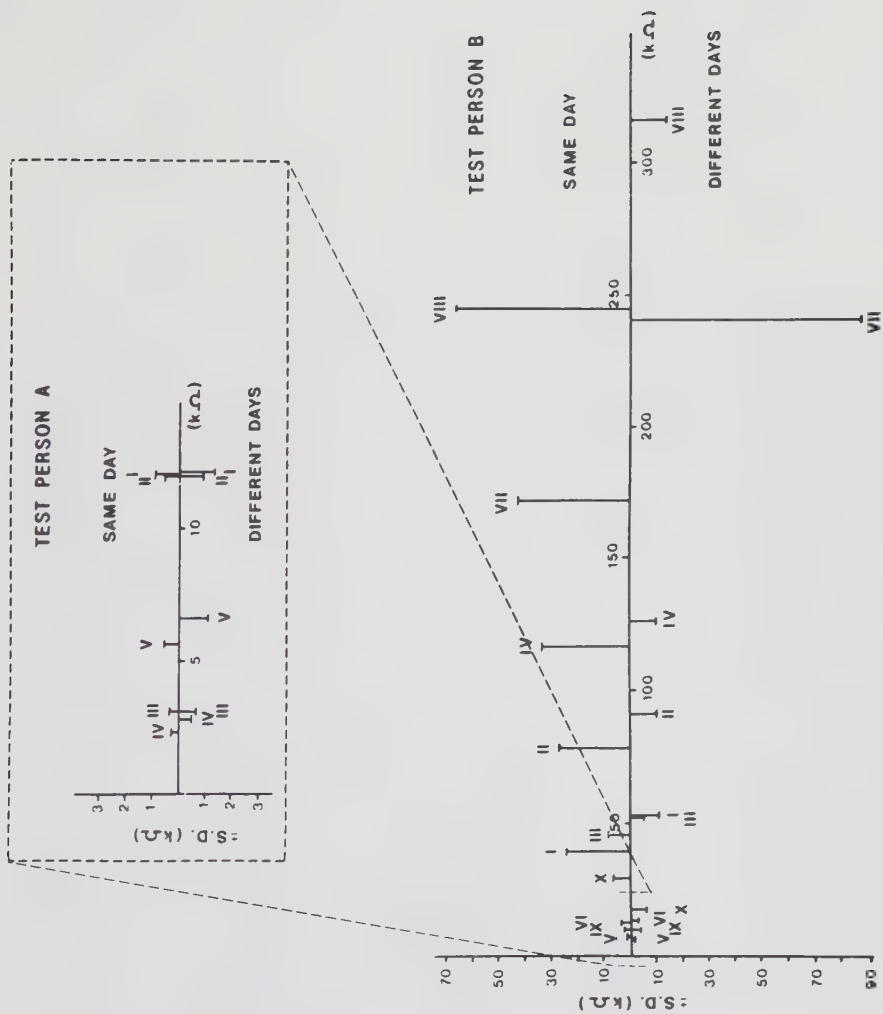


Fig. 2.

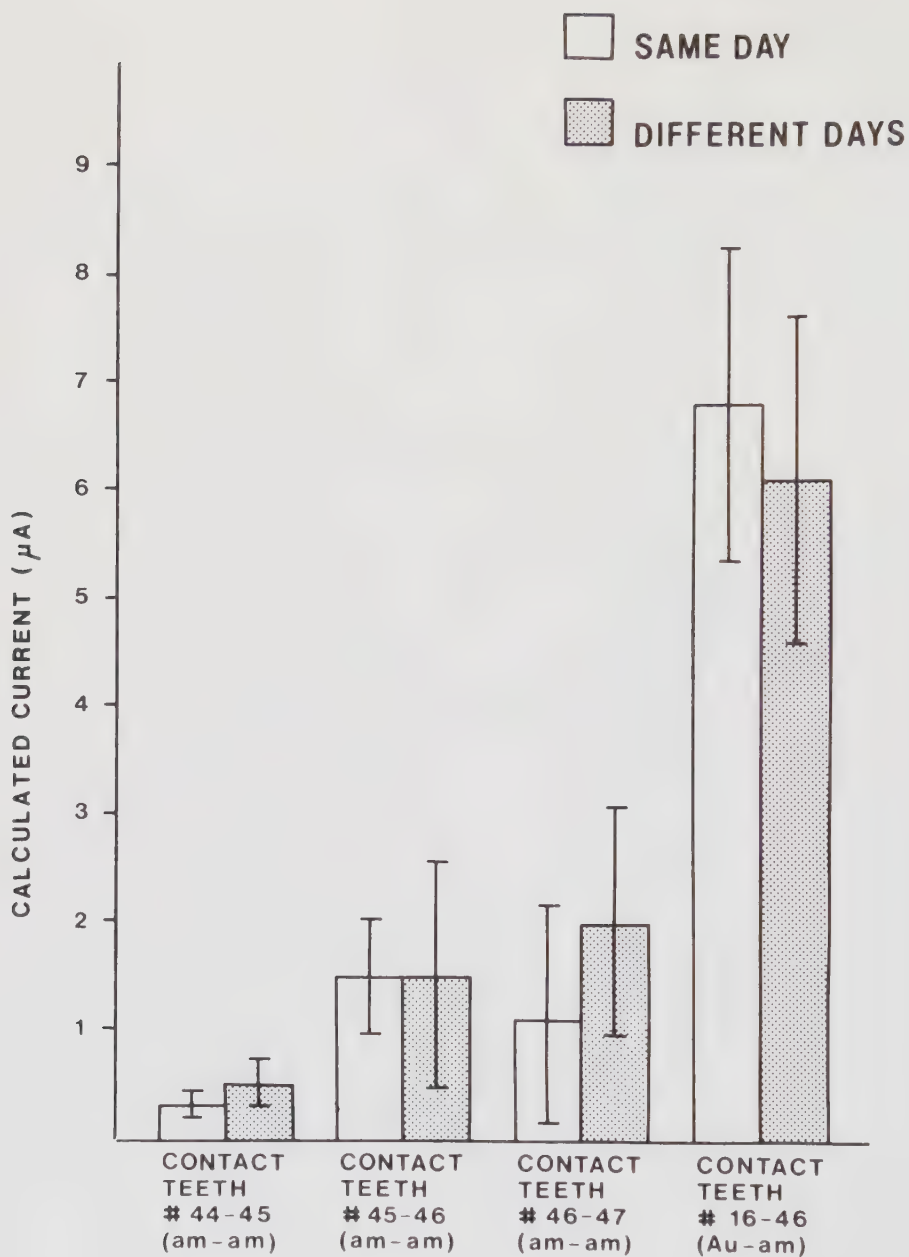


Fig. 3.

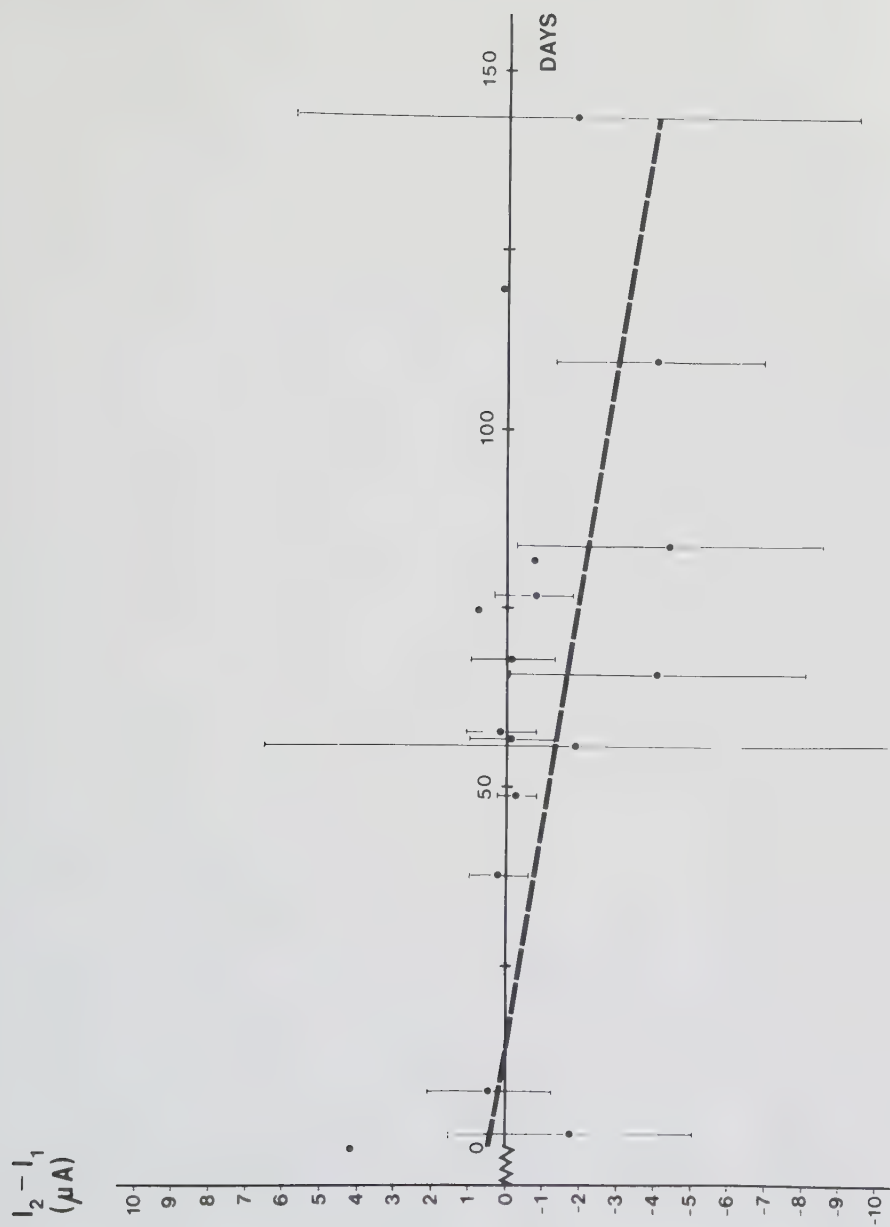


Fig. 4.

ORAL GALVANIC ACTION AFTER TREATMENT WITH EXTENSIVE
METALLIC RESTORATIONS

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Running head: Galvanic action after restorative care

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Oral galvanic action after treatment with extensive metallic restorations. Acta Odontol. Scand.

An epidemiological study was performed in 250 persons who five years previously had been treated with extensive metallic reconstructions.

To gain representative information these persons were selected at random from three Local Social Insurance Offices in different parts of Sweden.

Those person, who in a questionnaire reported symptoms that could be alleged to have been caused by oral galvanic actions, were offered free clinical examination including quality evaluation and free measurements of potentials and polarizations of the metallic dental restorations.

Persons from a subgroup to this study not suffering from any oral discomforts were chosen as a control group.

Comparisons between the two groups were made in regard to current creation at metallic contacts, clinical quality and mucosal conditions.

In none of the statistical analyses performed, differences could be shown between the groups. A tendency to higher amounts of restorative care at comparatively lower level of technical quality could, however, be noticed in the group of persons with oral symptoms which they themselves associated with oral galvanism.

Key words: epidemiology; electrochemistry; oral galvanism

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Currents created by intraoral galvanic cells have been described as causing pain and discomfort (5,10,11,16) as well as oral mucosal lesions (2). In some cases malignant transformations have been shown to develop in such lesions (2).

In literature there have also been suggestion that oral galvanic actions may cause a variety of general medical symptoms and diseases (6,14). No direct evidence has, however, been presented to prove the existence of systematic correlations of this type.

The number of reported cases with local or general symptoms alleged to have been caused by oral galvanism is small in comparison with the number of other technical and biological complications associated with restorative treatments, including fixed appliances (4,8,9,13,17,19).

A method for in vivo-measurements of the mixed potentials and polarizations of metallic dental restorations, that allows for calculation of the currents created, has been presented by Bergman, Ginstrup and Nilner (3), who have also described equipment for such measurements.

Bearing the above in mind, and also the fact that recently oral galvanism has received wide public attention, it was considered worth performing an epidemiological study on the incidence of oral galvanism among persons who had received treatments with extensive metallic restorative dental appliances.

MATERIALS AND METHODS

From the records of the Swedish Local Social Insurance Offices of three counties (Kronoberg, Malmö city and Örebro) a total of 250 persons were selected at random among 7058 persons who five years prior to the beginning of this study - i.e. in 1974 - had received extensive restorative dental treatment. The number of persons selected from the individual counties are given in Table 1, together with the number of persons participating in the study. In 1974 all the selected persons had received restorative treatment including fixed crowns and/or bridges. The mean number and bridge units per clinically investigated person was 7.0 with a standard deviation of 3.9 units. In addition 4 persons had also received treatments with removable partial dentures.

Each of the individuals selected received a questionnaire designed to obtain information about their oral hygiene habits as well as their attitudes towards dental care. A number of questions were also asked in order to collect information about recent dental care and whether or not the respondents had experienced any signs or symptoms of oral galvanism in association with the dental care received five years previously. (Copies of the questionnaire will be provided on request). The questionnaire was sent out with an explanatory letter stating that its aim was to determine the incidence of problems, discomfort and complications associated with the clinical usage of cast metallic dental restorative materials. A second questionnaire and letter was sent out to those persons who did not respond to the first one.

As can be seen in Table 1, 19 of the 250 selected persons did not respond at all. These persons could not be traced or refused to participate and therefore had to be omitted. Of the rest of the selected group, another ten persons had to be excluded for various reasons: four had deceased, one was mentally and

physically disabled, and two returned the questionnaire unanswered. Finally three persons had to be omitted because the dental appliances placed in 1974 were no longer in situ. The age and sex distributions of the selected persons are given in Table 1.

The answers from the remaining 221 questionnaires were examined and all persons who had given answers indicating symptoms of oral galvanism, were contacted and offered free clinical examination including quality evaluation of their metallic restorations (20) and free measurements of potentials and polarizations (12). The total number of this group of contacted persons was 21, of whom 4 came from Kronoberg, 13 from Malmö and 4 from Örebro.

From information gained during discussions with the individual subjects, it was discovered that only 14 persons needed to undergo potential and polarization measurements. Of the group of seven persons not selected for further examination, three were found to have misunderstood the questionnaire and to have their oral discomfort in clear association with other conditions than those relevant to this study. Four persons underwent the clinical examination but did not appear at the subsequent appointment when potential and polarization measurements were to be performed. Neither did these persons express any interest in such measurements when later contacted individually.

A subgroup to this study consisting of 109 persons, underwent separate clinical examination (7). In this subgroup 102 persons showed neither clinical signs nor any symptoms of oral galvanism or associated conditions. Among this group of persons 16 were randomly selected to undergo complete potential and polarization measurements and thus serve as a control group.

A statistical analysis (Student's t-test) was performed to study the relationship between the quality, as given by the CDA-rating system (20), of the cast restorations of the persons in the control

group and the remaining persons without signs or symptoms of oral galvanism. Another analysis was performed on the relationship between the dental habits and attitudes to dental care between these two groups. The results of these analyses did not show the presence of any statistically significant ($p > 0.05$) differences between the two groups.

The methods and instrumentation used at the measurements of the potentials and polarizations have been described in detail by Bergman et al (3) and Nilner et al (12). For the two groups of persons who underwent clinical examinations information was obtained from the files of the dental insurance system with regard to the brand of dental gold alloy used in the manufacture of their respective appliances.

RESULTS

The results of the questions in the questionnaire dealing with symptoms of oral galvanism are given in Tables 2, 3 and 4 respectively.

When the results of Tables 2 to 4 are examined it is evident that about one fourth of those persons, who had received restorative treatment including extensive cast reconstructions, experienced one or more symptoms possibly associated with oral galvanic actions. For one fourth of the persons with symptoms, these, however, appeared more than one month after a dental appointment.

As it is unlikely for delayed galvanic actions to appear under clinically unchanged conditions, those symptoms appearing more than one month after a dental appointment, were judged probably not to have galvanic origin. Therefore, the eleven persons with such delayed symptoms were excluded from the group of persons possibly ailing from oral galvanism.

The results of Table 4 show that in 21 persons,

the symptoms which had appeared more or less directly after treatment had not disappeared at the five year control. As has been discussed above, among these 21 persons seven could be excluded after the initial discussion.

When dental habits and attitudes to dental care, as revealed by the answers to the questionnaire, were compared between the group of the remaining 14 persons and those claiming never to have felt any of the problems listed in Table 2, no systematic differences were detected.

The maximum possible intraoral galvanic current, as calculated from the recorded potentials and polarizations (3,12), are given in Fig. 1 for the group of persons with symptoms, as well as the control group.

The results in Fig. 1 clearly show the wide range of calculated intraoral galvanic currents in both the control group and the group of persons with symptoms.

A statistical analysis (Mann-Whitney U-test) was performed on the data given in Fig. 1. The result of this analysis did not show the presence of any statistically significant differences ($p > 0.05$) between the calculated maximum intraoral galvanic currents in the two groups.

The results of the clinical evaluations of the persons in the symptom group, the control group ($n = 16$) and the complete group of persons without symptoms ($n = 102$) are given in Table 5 and for the symptom group and the complete group only, in Fig. 2. A statistical analysis (Student's t-test) was performed on the data given in Table 5. No statistically significant differences were obtained.

The brands of gold alloy used in the manufacture of the dental appliances were not found to differ in any systematic way at all between persons in the symptom and control groups.

DISCUSSION

The existence of oral electrochemical corrosion processes and the presence of currents created by such processes and by the simultaneous use of different metallic dental restorative materials have long been known (16).

Recently this phenomenon - oral galvanism - has been claimed to be the cause of a wide variety of oral symptoms as well as diseases in other parts of the body (6).

Further, especially in Sweden, an increasing number of persons have lately, probably at least partially, due to a remarkable public interest in this subject, maintained that they suffer from oral galvanism. In doing so they name a wide range of oral as well as general discomforts and pains in their self diagnosis.

From existing literature, it can unfortunately not be concluded to what extent symptoms are associated with oral currents. With the opportunity at hand, however, of using suitable methods for calculating currents from intraoral bimetal cells, the need was strongly felt to perform an epidemiological investigation into the incidence of the phenomenon of oral galvanism.

The sample chosen was person selected at random from the records of Swedish Local Social Insurance Offices. These records made it possible to select persons, who at a certain previous time, had been treated with a certain type of dental reconstruction. The National Dental Health Insurance System has a regulation which states that all care given during a certain period by one dentist has to be examined and approved in advance when assessed to be extensive and to exceed a certain cost limit. At the time chosen (1974) for the beginning of the treatments under study this limit was 2000 Swedish crowns ($\approx$ 500 US \$). Therefore persons who in 1974 had received dental

treatment including metallic restorations at a total cost of not less than 2000 Sw. Cr. were chosen as the group to be investigated.

The area for selection of persons covered three separate Swedish government districts (the city of Malmö and the counties of Kronoberg and Örebro). They were chosen in such a way as to cover existing kinds of such districts ranging from urban to rural ones. It was considered that the selection of government districts and the random nature of the population sample allowed for valid conclusions to be drawn for Swedish residents treated with extensive dental metallic reconstructions.

The main reason for choosing persons who had undergone extensive restorative treatments almost invariably including some type of cast dental gold alloy five years before the beginning of this study, was to make likely that in the oral cavities of several of these persons restorative treatments including other metallic systems had also been performed. This ought to have given rise to permanent or intermittent metallic contacts known possibly to generate intraoral currents (3).

In the questionnaire used those parts dealing with the interviewees' experience of dental care were designed to survey those symptoms which most often have been reported to be associated with intraoral currents (3, 11). The method used for collecting information about habits and attitude to dental care was considered justified as the sample was spread over a geographically large area (18).

The response rate achieved in this study was unusually high (88.4 %). As the nonresponding persons did not seem to differ significantly from the respondents it was concluded that the part of the study concerning the questionnaire enabled relatively precise assessments to be made.

The method used to determine in vivo potentials and polarizations (3) has previously been tested and

found to provide a basis for accurate calculations of the magnitudes of oral currents (12). Likewise the methods employed in the clinical part of this study were regarded to be sufficiently accurate (15).

None of the persons with symptoms of oral galvanic action had actively been seeking dental or medical care for these symptoms but obviously merely considered them to be irritating. Bearing this in mind, in a population of persons receiving restorative dental treatments including extensive metallic appliances, the frequency of cases with a need for treatment of oral symptoms caused by oral galvanism should be below 5 ‰. When this estimated frequency is compared with those reported for other types of complications in association with fixed prosthetic treatments (8, 13, 17, 19) it must be considered to be of a comparatively low magnitude.

In addition, as has been mentioned above, certain soft tissues lesions have been shown to be associated with intraoral corrosive processes. As no such lesions were found at the clinical examinations of the selected group from the studied population, the prevalence of galvanically initiated such lesions should be below 1 %. Such a level is below those reported by Axell (1) for lichen planus and leukoplakia in a Swedish population. Whether this depends on differences in the populations studied or is an examiner effect cannot be determined.

A number of clinical as well as technical criteria have been tested for possible correlations with subjective symptoms of oral galvanic actions. No such statistically significant correlations could, however, be established. This points to the fact that oral discomforts of galvanic origin may be of a multifactorial nature, or that such discomfort has a single cause not studied here. Bearing in mind the wide range of clinical and technical criteria studied, if the latter possibility is true, such a single cause is probably of general medical or

physiological nature.

Of the correlations studied, the most striking ones were those between the presence of oral discomfort of possible galvanic nature and the quality as well as the quantity of the restorative treatment given (Table 5 and Fig. 2). One can not hesitate from speculating that among this group of persons with symptoms the local level of resistance might at least to a certain extent have been affected in a negative way by the relative massive amount of care that had been given at a relatively low level of quality. Consequently, the currents always present in oral bimetal cells could have been made noticeable to these persons.

In conclusion the finding of this study supports the suggestion by Bergman et al (3) that the question as to whether galvanism causes symptoms is mainly a function of biological threshold values.

Acknowledgement. For valuable help and discussions on the statistical aspects of this study we wish to thank Mr. Bo Zöger.

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Age and sex distribution of persons selected for the study of oral galvanic action after treatment with extensive metallic restorations and frequencies of reasons for omission of selected persons from the study

Type of selected person	City of Malmö						County of Kronoberg						County of Örebro						Total	
	Male		Female		Male		Female		Male		Female		Male		Female					
	n	Age mean S.D.	n	Age mean S.D.	n	Age mean S.D.	n	Age mean S.D.	n	Age mean S.D.	n	Age mean S.D.	n	Age mean S.D.	n	Age mean S.D.	n	Age mean S.D.		
Used in the study	72	53.6 ± 12.4	61	53.6 ± 13.5	20	53.3 ± 14.6	24	50.6 ± 12.5	22	55.8 ± 12.7	22	63.7 ± 9.1	114	54.0 ± 12.8	107	55.0 ± 13.2				
Omitted because dental appliance no longer in situ	2	49.0 ± 18.4	1	48	0	0	0	0	0	0	0	0	2	49.0 ± 18.4	1	48				
Omitted because of death	1	66	0	0	0	0	0	0	2	69.5 ± 9.2	1	74	3	68.3 ± 6.8	1	74				
Omitted because of mental and physical disability	0		0	0	0	0	0	0	1	74	0	0	1	74	0					
Omitted because of only blank answers given in questionnaire	0		1	51	0	0	0	0	0	0	1	47	0	0	2	49.0 ± 2.8				
Omitted because of refusal to participate	2	55.0 ± 1.4	5	60.0 ± 16.2	0	0	0	0	0	0	0	0	2	55.0 ± 1.4	5	60.0 ± 16.2				
Omitted because not traceable	5	45.2 ± 14.9	0		3	48.0 ± 9.5	3	54.0 ± 9.5	0	0	1	51	8	46.3 ± 12.4	4	53.3 ± 7.9				
TOTAL	82	53.2 ± 12.5	68	53.9 ± 13.5	23	52.6 ± 14.0	27	51.0 ± 12.1	25	57.6 ± 13.0	25	63.0 ± 9.7	130	53.9 ± 12.9	120	55.1 ± 13.1				

Table 2.

Frequencies of responses given to question: "Have you experienced any of the following problems after a dental appointment?" (n = 221)

Response alternative	Number of responses given	Percentage of responses given
Metal taste	44	19
Oral smart	7	3
Oral pain (that could not be cured by the dentist)	5	2
Battery taste	7	3
No such problems	165	72
No response	3	1

Table 3.

Frequencies of responses given to question: "How long after the dental appointment did the problems appear?"

Response alternative	Number of responses given	Percentage of responses given
Within the first day	25	11
Within 1 to 7 days	5	2
Within 1 to 4 weeks	3	2
After more than one month	11	5
No response	177	80

Table 4.

Frequencies of responses given to question: "How long did it take for the problems to disappear?"

Response alternative	Number of responses given	Percentage of responses given
Some days	20	9
Some weeks	7	3
Some months	2	1
Problems have not disappeared	21	10
No responses	171	77

Table 5.

Results of clinical quality evaluation, according to the CDA-rating system, performed on cast crowns in persons with and without certain oral symptoms. (R = excellent, S = acceptable, T = replacement needed for preventive reasons and V = replacement must be done immediately because damage is now occurring)

Patient group	n	Number of R-crowns		Number of S-crowns		Number of R + S-crowns (Satisfactory)		Number of T-crowns		Number of V-crowns		Number of T + V-crowns (Not acceptable)	
		mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
With symptoms	14	0.86	1.88	4.07	3.10	4.93	3.29	0.36	0.84	0.71	1.20	1.07	1.86
Without symptoms (control)	16	1.25	2.02	3.69	2.75	4.94	3.68	0		0.56	1.50	0.56	1.50
Without symptoms (total)	102	1.03	1.61	3.02	2.10	4.05	2.54	0.16	0.93	0.29	0.86	0.45	1.23

LEGENDS

Fig. 1 Distribution of calculated maximum current in persons with and without certain oral symptoms.

Fig. 2 Distribution of mean not acceptable (with S.D.) and mean satisfactory (with S.D.) crowns in persons with and without certain oral symptoms.

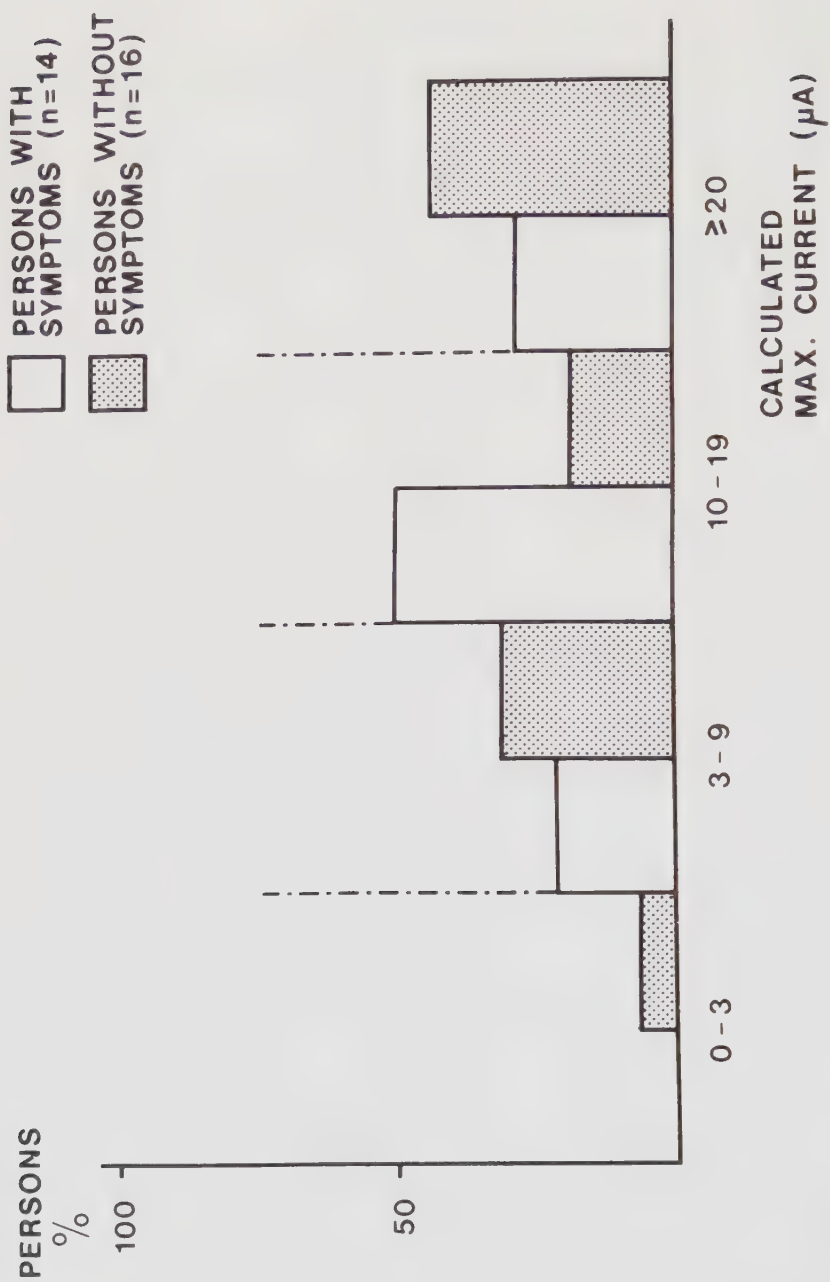


Fig. 1.

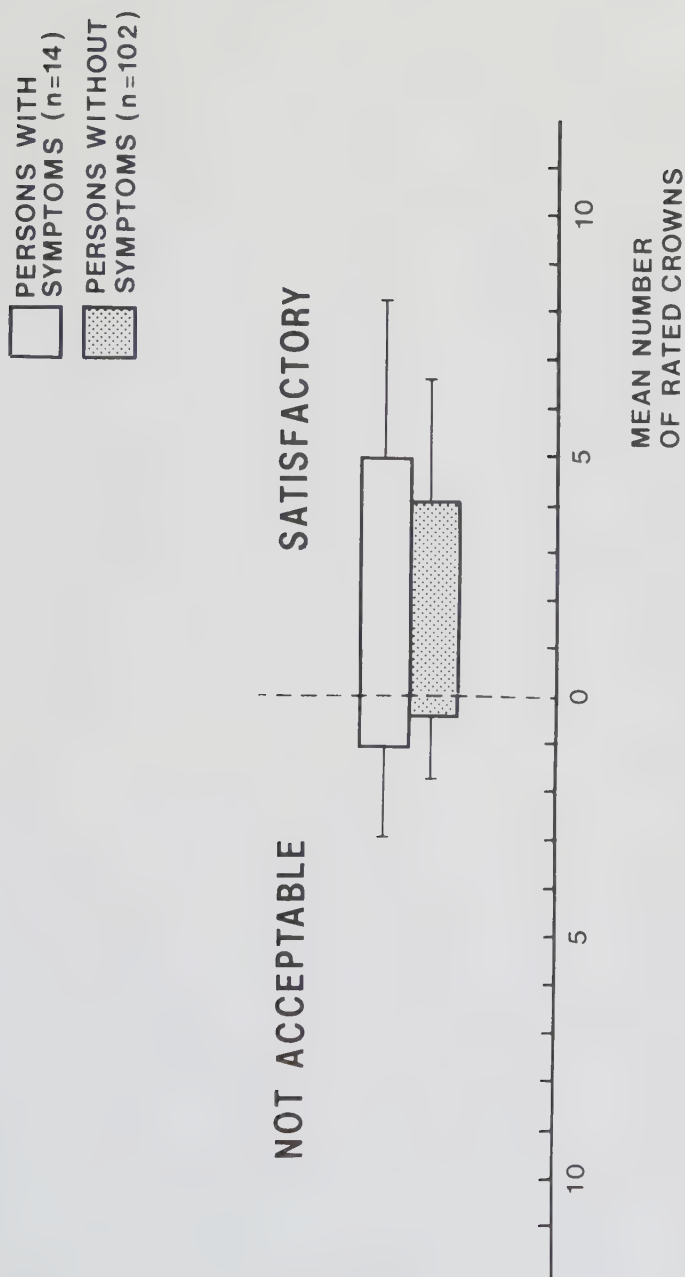


Fig. 2.

INTRAORAL CURRENTS AND TASTE THRESHOLDS

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Key words: Electrogustometry, taste acuity,
electrochemistry, galvanic action

Abstract

A group of patients, with oral symptoms such as oral smart, battery taste and metal taste, were examined to study the relationship, if any, between intraoral currents, created at metallic contacts between restorative materials, and taste perception thresholds.

The patients were examined with an electrogustometric method for determination of taste threshold levels. Further the intraoral currents of these patients were calculated from data obtained at potential and polarization measurements.

Comparisons were then made between groups of subjects with and without oral symptoms.

The results of this study indicate that patients with certain oral symptoms have lower threshold levels for electric taste stimulation than persons in a control group selected at random.

No differences were, however, observed between the magnitudes of intraoral currents in the two groups.

Sammanfattning.

Eventuella samband mellan tröskelvärden för elektriskt stimulerad smak och ström som alstras vid kontakt mellan dentala metalliska rekonstruktionsmaterial har studerats hos en grupp patienter, som uppgav sig lida av symptom av typ batterismak, metallsmak och sveda i munnen.

Tröskelvärden för smak bestämdes med elektrogustometri och styrkan av intraoralt alstrade strömmar beräknades efter mätning av potentialer och polarisationer.

Jämförelser gjordes mellan resultaten från symptomgruppen och en slumpvis utvald kontrollgrupp av personer utan subjektiva orala besvär.

Dessa jämförelser visade att patienter med subjektiva orala symptom hade lägre tröskelvärden för elektrisk smakstimulering än personer utan sådana symptom.

Någon skillnad kunde icke påvisas mellan styrkan av alstrade strömmar i de båda grupperna.

INTRODUCTION

The insertion of contacting dental metallic restorations in the oral cavity creates currents. A method which allows for the calculation of the magnitude of such currents has been presented (Bergman, Ginstrup and Nilner 1978). In a separate study the clinical applicability of this method has been demonstrated (Nilner, Glantz and Zöger 1981 b).

Some of the clinical effects of these intraoral currents have recently been explored in an epidemiological study (Nilner, Glantz, Ryge and Sundberg 1981 a), which shows among other things a relatively frequent (about 20 per cent) appearance of temporary as well as permanent metal taste sensations in association with extensive dental care. A relationship between intraoral electric currents and taste perception has long been known and was for example reported in the literature as early as 1754 (Sulzer in Bujas 1971). In a study of the bitter taste-testing ability among a group of professional beer testers Nyquist (1949) discussed the possibility that certain tongue changes could be caused by galvanic currents. Further he proposed that if these currents caused changes in the tongue they might also affect the taste buds.

To obtain a quantitative measure of taste, Krarup (1958) used electric stimulation methods and constructed the so-called Electrogustometer. This device has been used and modified by several investigators. For review see Nilsson (1978). Nilsson (1978) studied the taste perception on different areas in the oral cavity in relation to age, sex, denture wearing and smoking.

With the above mentioned facts in mind and in order to reveal the existence, if any, of a relationship between intraoral currents created at metallic contacts and taste perception thresholds, it was considered worthwhile examining a group of patients both with

an electrogustometric method and methods for determination of potentials and polarizations of metallic dental restorations.

MATERIALS AND METHODS

The material consisted of 62 persons from a body of patients, referred consecutively 1978 and 1979 to the Departments of Prosthetic Dentistry and Oral Surgery at the School of Dentistry in Malmö. All the persons experienced symptoms alleged to be caused by oral galvanism. As a control 15 persons were randomly selected from a group of totally 102 persons who took part in an epidemiological investigation (Nilner et al 1981 a) and had no history of symptoms or discomfort from the oral cavity. The sex and age distribution of the persons in the patient and control group are presented in Table 1.

All subjects underwent measurements of potentials and polarizations of their metallic reconstructions in the oral cavity to allow the calculation of the magnitude of the current created at metallic contacts (Nilner et al 1981 b). In the analyses of the data each patient was merely assigned the highest value calculated.

The subjects were also submitted to measurements of their electrical taste thresholds - an inverse measure of the sensitivity for the taste sensation elicited at electrical stimulation on areas where taste buds are present. The same electrogustometer and method as described by Nilsson (1979) were used. The electrogustometer gives stimuli of 1 - 1000 μ A in 76 steps with a current increase of 9.65 % (0.04 log units) between successive steps (table 2).

The taste thresholds were measured on four representative areas in the oral cavity namely on both sides of the tip of the tongue and on the soft and hard palate at the midline (Nilsson 1978). The subjects were also requested to characterize the taste sensation they perceived at the testing with

electrogustometry.

As two patients could not cooperate in the electro-gustometric test they were omitted. The remaining 60 patients are below referred to as the symptom group.

Statistical methods

In comparing the distribution of calculated currents in the symptom group and the control group as well as the distribution of the electrical taste thresholds in the two groups, Mann Whitney U-test was used (Sigel 1956).

In comparing both the characterization of the taste sensation perceived in the two groups and the relation of the calculated currents with the taste thresholds, χ^2 -test was used (Siegel 1956).

The following levels of significance have been applied:

No significant differences	$p > 0.05$
almost significant differences	$0.01 < p < 0.05$
significant differences	$0.001 < p < 0.01$
highly significant differences	$p < 0.001$

RESULTS

The highest current calculated between restorations at contact were 159 μ A in the symptom group and 49 μ A in the control group. The distributions of the subjects according to the maximum current calculated for each person are presented for both groups in Fig.1. No statistically significant difference was found between the distributions in the two groups.

The distributions of the thresholds for electrical taste on the examined areas in the symptom group are presented in Fig. 2. In spite of great individual variations of thresholds a tendency to increased thresholds in older individuals can be seen.

The median thresholds for the electrical taste were lower on each examined area in the symptom group than in the control group. The distributions of the thresholds in the control group and for the subjects above the age of forty in the symptom group are visualized in Fig. 3. The thresholds for the three subjects, under 40, in the symptom group are excluded in Fig. 3 to allow for accurate comparisons between the groups.

Statistical analyses revealed that the thresholds on the right side of the tip of the tongue in the symptom group differed significantly from corresponding values in the control group. Almost significant differences were shown between the thresholds on the left side of the tip of the tongue in the two groups but no such differences were found when comparing the thresholds on the soft palate and the hard palate respectively between the two groups.

The electrical stimuli on the tip of the tongue elicited the following taste sensations in the symptom group: battery taste in 34 %, metallic taste in 31 %, a pungent taste in 12 %, salty in 11 % and sour in 5 %. The remaining 7 % could not define the taste. Corresponding figures in the control group were: battery taste in 11.8 %, metallic taste in 41.2 %, salty taste in 23.5 % and 23.5 % of the subjects could not define the taste. No statistically significant differences were shown to exist between the two groups in perceived taste sensations at the electrogustometric test.

In the symptom group 37 % of the subjects reported that the electrical taste was the same as a phantom taste which was one of their symptoms.

In 6 patients (10 %) in the symptom group no metallic contacts could be made i.e. currents of the type studied could not be created and hence not calculated. Corresponding figure for the control group was 6 %. Maximum calculated currents exceeding

the lowest established threshold for electrical taste were found in 63 % of the subjects in the symptom group and in 47 % in the control group. In the remaining 27 % of the subjects in the symptom group and the 47 % in the control group the maximum calculated current between contacting dental metallic restorations did not reach the lowest value of the threshold determined for any of the different areas (Fig. 4).

The symptom group and the control group did not differ statistically significantly with respect to the correlation between maximum calculated currents and taste thresholds.

DISCUSSION

In investigations performed on clinical material caution is advisable when drawing conclusions that could be applied to a wider section of the population. Pre-requisites should be, that the drop-out rate among the patients selected is minimized and that all patients are submitted to, and complete, equivalent examinations.

In this study two patients had to be omitted from the originally selected group. They were excluded because of their inability to cooperate in electro-gustometric test. Both of them had a disposition to give too many "false alarms" i.e. they reported taste when just the electrode was applied to the area to be examined but before the current had been switched on. This tendency was true for all areas examined in both the excluded persons, which is in contrast to the experience that some patients may report taste for only some of the areas, when not electrically stimulated (Nilsson 1978).

Further, as this investigation was carried out as a comparative study of a symptom group and a control group selected at random and all members of these groups underwent the same examinations, it may still

be considered justifiable to draw conclusions from differences observed between the two groups.

Distribution by sex differs between the two groups studied in so far as the women are in a clear majority in the symptom group whilst males and females are more evenly distributed in the control group (Table 1). This could reflect the possibility that women more often than men suffer from symptoms allegedly caused by galvanic action in the oral cavity. Such a condition is, however, contradicted by the results from another study performed on randomly selected persons who reported symptoms to the same extent in both sexes (Nilner et al 1981 a). Rather, the overrepresentation of women is, if not purely coincidental, probably caused by an enhanced tendency among women to seek dental treatment, as discussed for other fields of dentistry (Richards 1971 and Helöe & Helöe 1975).

As can be seen in Fig. 1 the distribution of the subjects by calculated maximum current is skew, indicating that the underlying population sample is also distorted. This led to the selection of non-parametric techniques for the statistic analysis, as they do not assume that the scores under analysis are drawn from a normally distributed population (Siegel 1956). Nilsson (1978) discussed why non-parametric tests are also suitable when testing the results of electrogustometry.

In previous investigations the method chosen for measurements of potentials and polarizations, and hence the calculation of intraoral currents (Bergman et al 1978), as well as the method for determination of the taste acuity (Nilsson 1978) have been shown applicable in clinical work, as has been proved in separate methodological studies (Nilner et al 1981 b and Nilsson 1978). Because of the construction with a small increase of current between successive steps, the electrogustometer used is well fitted to allow

for accurate comparisons between thresholds and the currents created at metallic contacts in the oral cavity. Further the examinations were performed by the same examiners throughout the whole study to avoid biasing of the results.

According to Krarup (1965) difficulties may arise at electrogustometric tests with currents exceeding 300 μ A ($\approx$ 62 steps), as it is uncertain whether it is only a taste stimulation or if other receptors are affected. This is why the tests and the documentation of the results in Figs. 2 and 3 end at 65 steps.

The electrical taste thresholds among the group of patients with certain oral symptoms were lowest on the tip of the tongue, followed by the soft palate and highest on the hard palate. The increase in the thresholds in older individuals was more pronounced on both the soft and hard palate than on the tip of the tongue (Fig 2). These findings are in line with the results from previous studies of a population of healthy individuals of similar age (Nilsson 1979).

It is, however, obvious that the threshold values for electrical taste are lower for the patients with oral symptoms than are corresponding values in the control group (Figs. 3A and B), which indicate higher sensibility to electrical stimulation. As previous studies have shown lower thresholds in younger individuals three individuals, one of whom was only 17 years old, were excluded from the symptom group when comparing the symptom group and the control group as mentioned above. This lends stronger support to the conclusion that the members of the symptom group have a lower threshold for electrical taste stimulation than the persons in the control group.

At comparisons of the taste thresholds on the soft palate and the hard palate between the two groups, no differences were however revealed in taste acuity. This finding could be the result of a relatively low number of tests for these areas as the palate was

difficult to test due to retching-tendencies in several of the test persons.

Finally, as has been found in previous studies (Nilsson 1979 and Tomiyama, Tomita & Okuda 1971) some test persons can characterize the taste sensation perceived at electrogustometric tests whilst others cannot. The two groups compared did not, however, differ in this respect even if it is noteworthy that whilst only 7 per cent of the symptom group could not characterize the taste, 23 per cent of the control group failed to define it. The latter figure corresponds well to that found by Nilsson (1979) when examining healthy individuals.

Moreover, 37 per cent of the members of the symptom group were convinced that the taste perceived at the test was the one they maintained to be one of their symptoms. This points to the possibility that electrical currents might be a contributory etiological factor to the patients' discomfort.

In conclusion the results of the present study indicate that patients with symptoms from the oral cavity exhibit on average a better electrical taste acuity than do persons without such discomforts, even if no statistically significant difference was shown between the group as regards the tendency of the maximum currents under study created in the oral cavity to exceed the lowest taste thresholds.

The comparisons between the two groups indicate that the degree of discomfort experienced from currents, created at metallic contacts in the oral cavity or in other ways applied is related to taste thresholds. These results imply that it might be of interest to study the relationship between currents created at metallic contacts in the oral cavity and the electrical taste thresholds individually.

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Table 1.

Distribution of the subjects by group, sex and age
(n = number of individuals and S.D. = standard deviation)

	female			male			total		
	n	age		n	age		n	age	
		mean	S.D.		mean	S.D.		mean	S.D.
POOLED PATIENTS	50	57.2 ± 11.1		12	55.7 ± 11.0		62	56.9 ± 11.0	
omitted because of lack of ability to cooperate in electro- gustometric test	2	64.5 ± 7.8		-	-		2	64.5 ± 7.8	
SYMPTOM GROUP	48	57.0 ± 11.2		12	55.7 ± 11.0		60	56.7 ± 11.1	
subgroups									
< 40 years	2	26.0 ± 12.7		1	30.0	-	3	27.3 ± 9.3	
41 - 50 years	9	46.6 ± 3.2		1	42.0	-	10	46.1 ± 3.4	
51 - 60 years	20	55.7 ± 3.0		7	56.4 ± 2.6		27	55.9 ± 2.9	
≥ 61 years	17	67.5 ± 6.3		3	67.0 ± 5.3		20	67.5 ± 6.0	
CONTROL GROUP	7	58 ± 8.9		8	56.9 ± 11.1		15	57.4 ± 9.8	

Table 2.

The grading of the electrogustometer with a factor between each step of 1.0965.

Step number = $25 \times \log \text{current (in } \mu\text{A)}.$

Current in $\mu\text{A} = 10^{(0.04 \times \text{step number})}$

(From Nilsson 1979)

Step	μA	Step	μA	Step	μA
0	1.00				
1	1.10	26	11.0	51	110
2	1.20	27	12.0	52	120
3	1.32	28	13.2	53	132
4	1.45	29	14.5	54	145
5	1.58	30	15.8	55	158
6	1.74	31	17.4	56	174
7	1.91	32	19.1	57	191
8	2.09	33	20.9	58	209
9	2.29	34	22.9	59	229
10	2.51	35	25.1	60	251
11	2.75	36	27.5	61	275
12	3.02	37	30.2	62	302
13	3.31	38	33.1	63	331
14	3.63	39	36.3	64	363
15	3.98	40	39.8	65	398
16	4.37	41	43.7	66	437
17	4.79	42	47.9	67	479
18	5.25	43	52.5	68	525
19	5.75	44	57.5	69	575
20	6.31	45	63.1	70	631
21	6.92	46	69.2	71	692
22	7.59	47	75.9	72	759
23	8.32	48	83.2	73	832
24	9.12	49	91.2	74	912
25	10.0	50	100	75	1000

Legends.

Fig. 1 Distribution of subjects, with and without symptoms, by calculated maximum intraoral current.

Fig. 2 The cumulative frequencies of subjects in per cent plotted against the thresholds in electrogustometric steps (Table 2) for the symptom group as a whole (A) and in different age groups (B-D) on the examined areas (○: tip of tongue, right side; ●: tip of tongue, left side; △: hard palate and ▲: soft palate).

Fig. 3 The cumulative frequencies of subjects, from the symptom group (s) and from the control group (c), in per cent plotted against the thresholds in electrogustometric steps (Table 2) for the different areas examined (A-D). Number of examined areas in the two groups were respectively:

A: $n_s = 57$, $n_c = 15$

B: $n_s = 57$, $n_c = 15$

C: $n_s = 49$, $n_c = 14$

D: $n_s = 48$, $n_c = 12$

Fig. 4 Distribution of the subjects in the symptom group and the control group by the relationship between maximum calculated intraoral current and the lowest determined threshold for electrical taste.

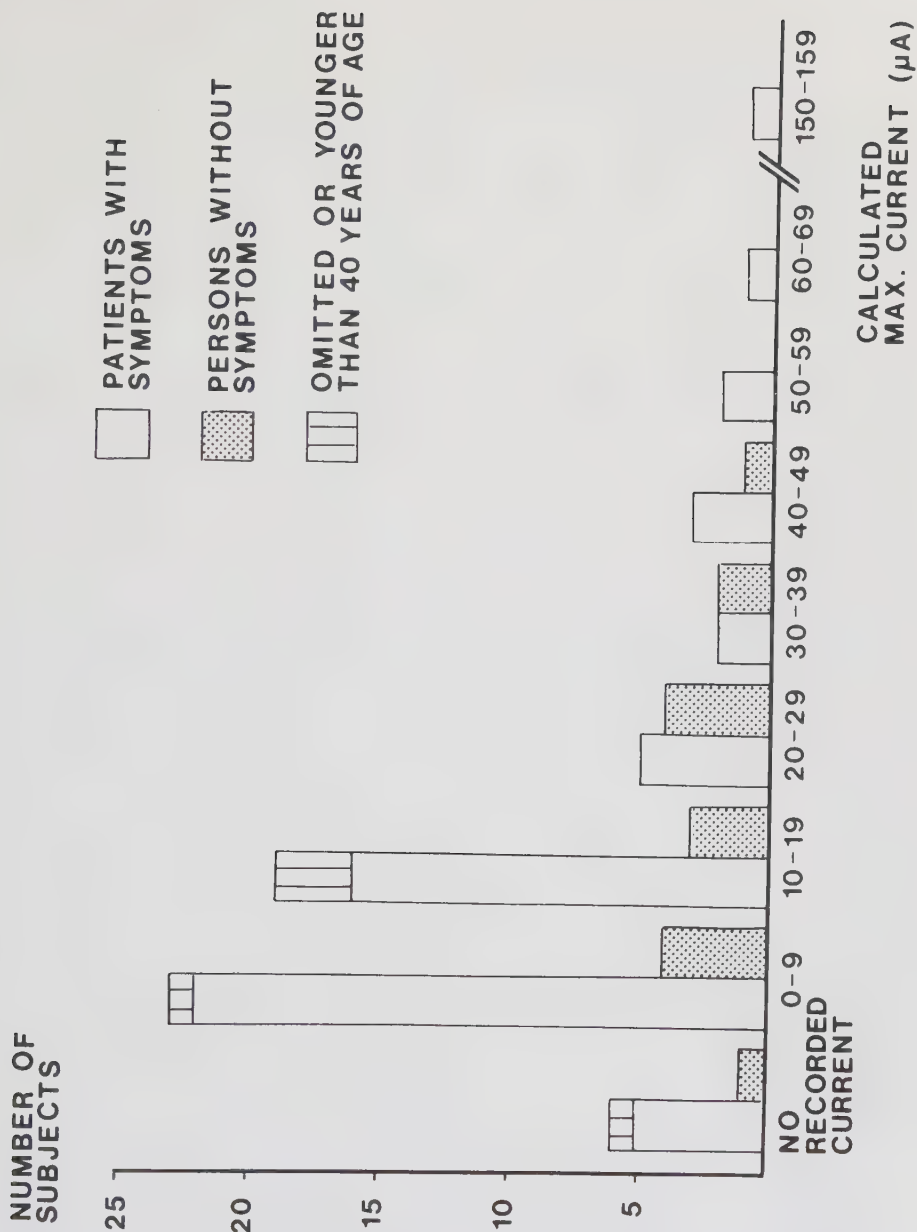


Fig. 1.

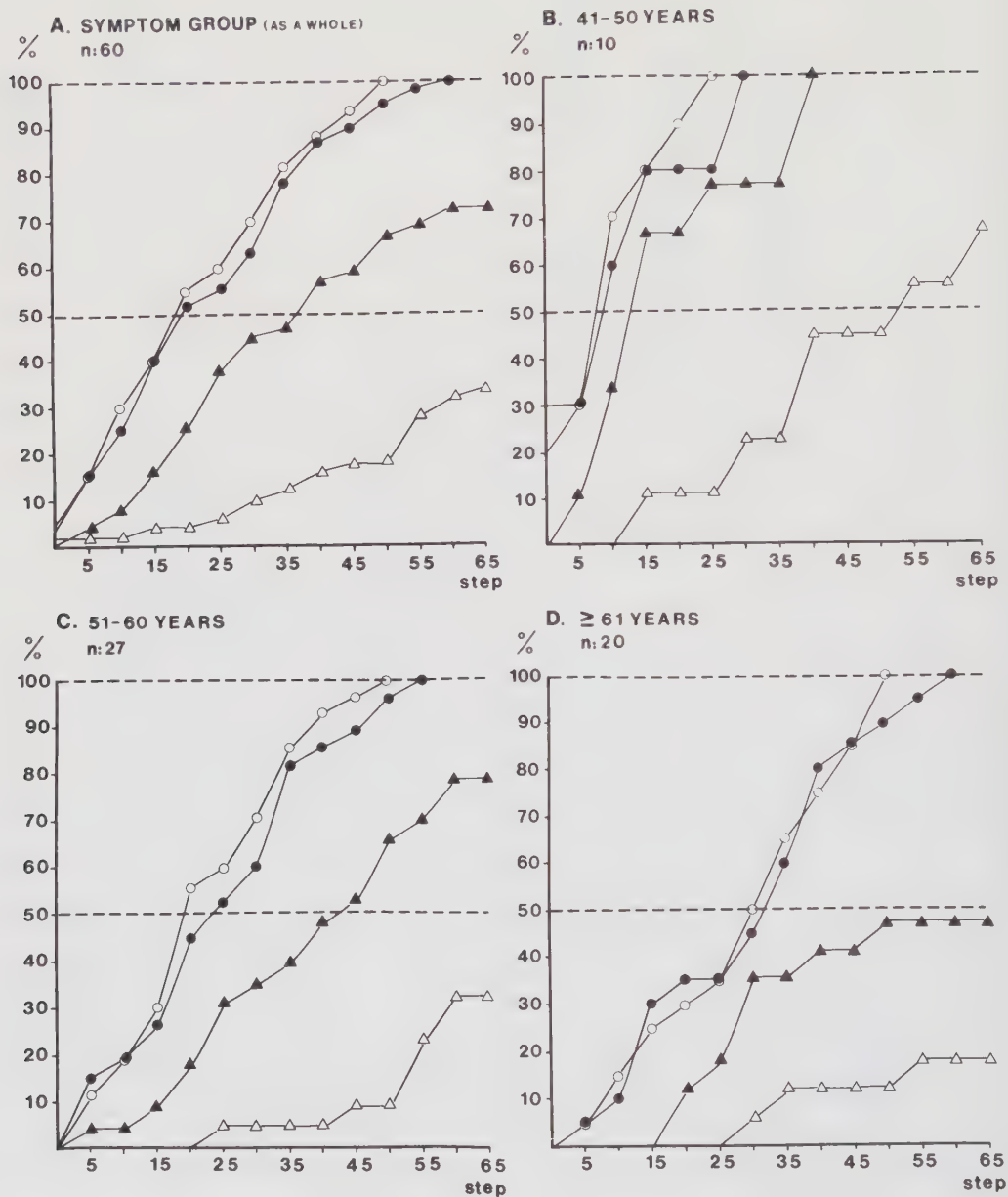


Fig. 2.

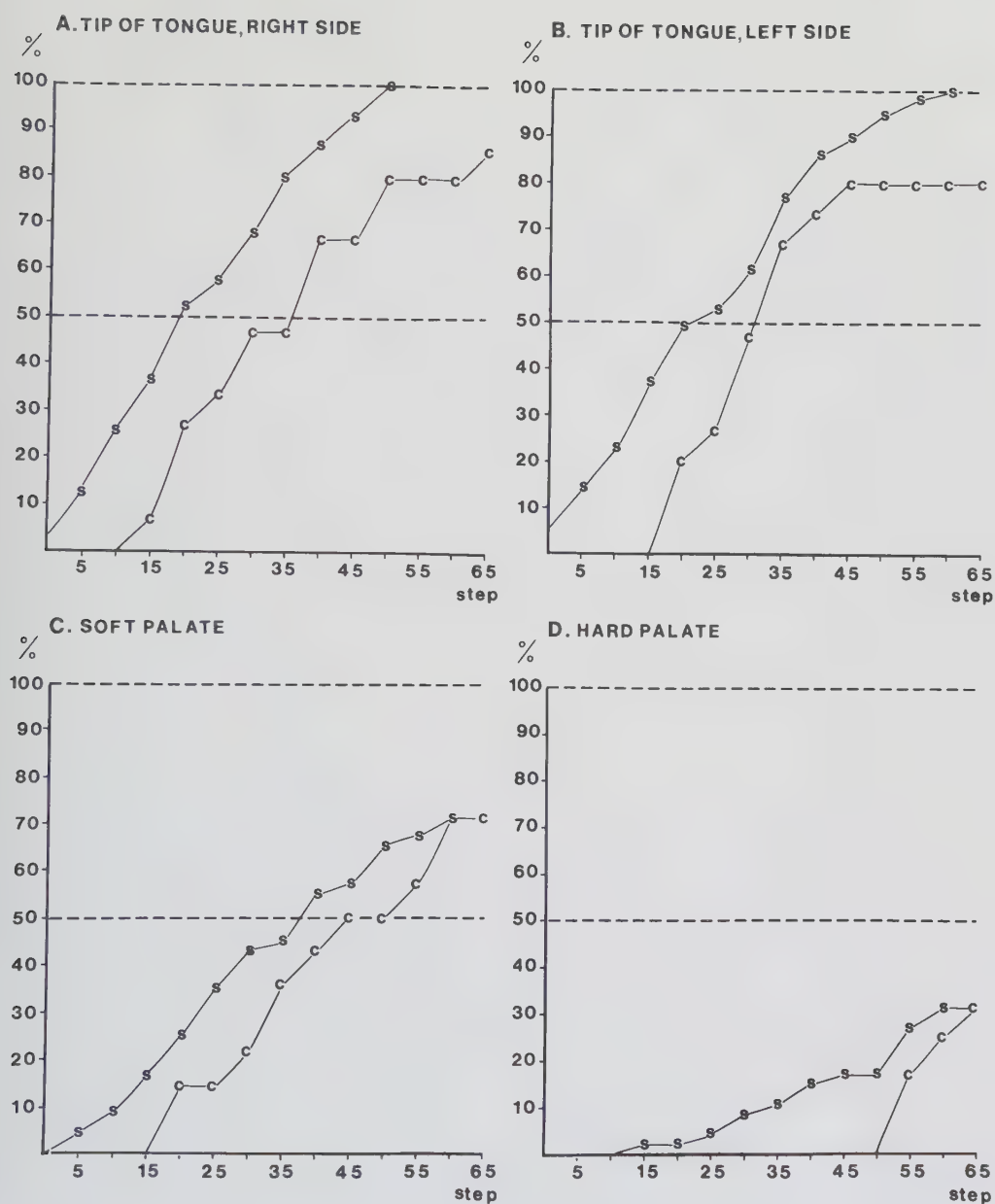


Fig. 3.

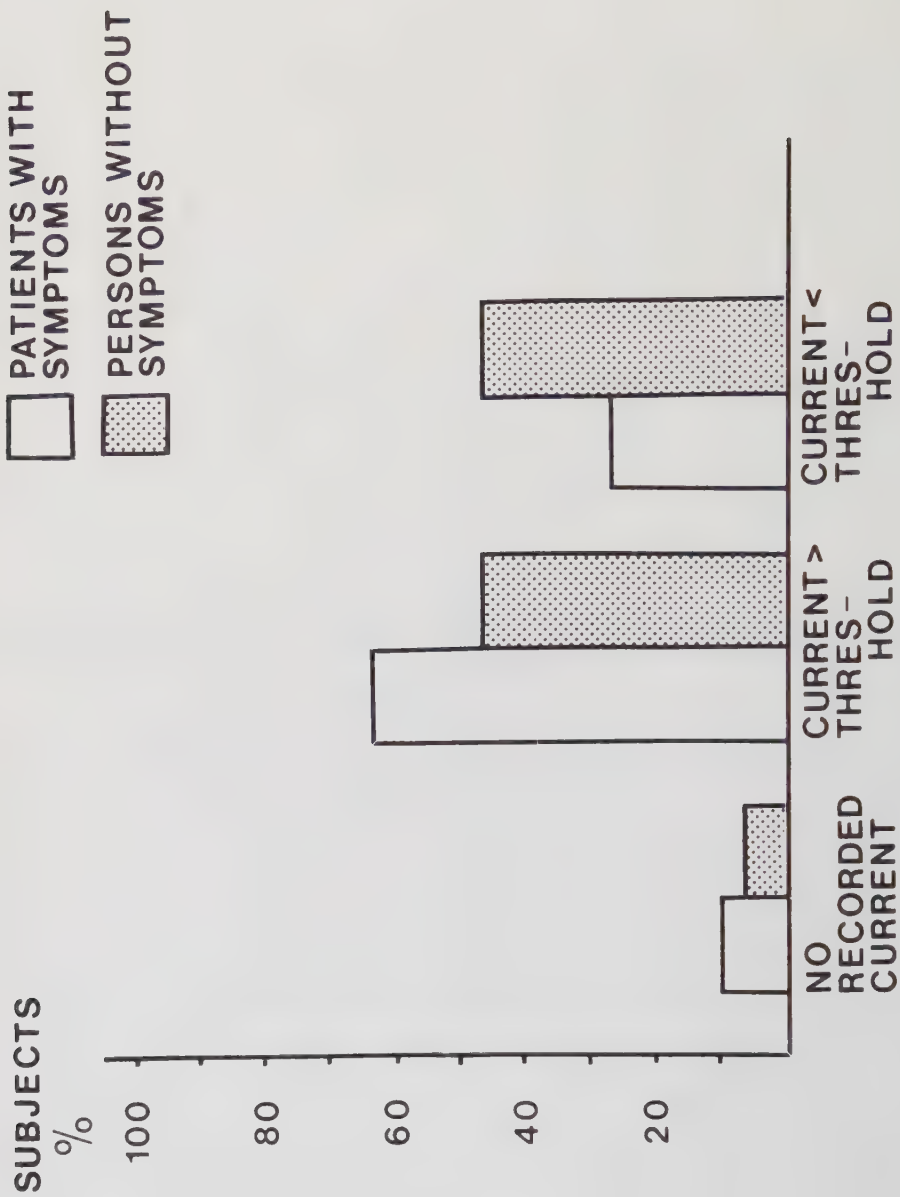


Fig. 4.

THE PREVALENCE OF COPPER-, SILVER-, TIN-, MERCURY-
AND ZINC-IONS IN HUMAN SALIVA.

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Key words: Electrochemistry, galvanic action, saliva
ion concentrations, toxicology

Abstract.

The amounts of certain metallic components (Ag, Cu, Hg, Sn and Zn) in saliva possibly derived from dental metallic restorations and due to galvanic actions, were studied in twelve females.

Three of these subjects were selected as they complained of certain oral mucosal symptoms and as, upon clinical examination, they were found to have enhanced galvanic action in terms of increased calculated currents at metallic contacts between restorative materials. The rest of the subjects did not experience any such symptoms and served as control groups by different criteria.

The saliva concentrations of the various metallic components were determined by atomic absorption spectrophotometry. They were not found to vary between the different groups.

The results do not forward any support to the view that galvanic action in the oral cavity can give rise to increased metallic contents in saliva. They therefore question the suggestion that increased galvanic action will cause general toxic reactions through the saliva.

Sammanfattning.

Hos totalt tolv kvinnor användes atomabsorptions-spektrofotometri för studier av salivkoncentrationerna av vissa metaller (Ag, Cu, Hg, Sn och Zn), vilka eventuellt utlösts från dentala metalliska ersättningsmaterial genom galvanisk aktivitet.

Tre av försökspersonerna deltog i undersökningen eftersom de uppgav sig lida av symptom från munhålan. Vid klinisk undersökning kunde höga strömstyrkor beräknas i metalliska kontakter hos dessa personer. Detta tolkades som förhöjd oral galvanisk aktivitet. Återstående nio försökspersoner uppgav sig icke ha några orala symptom. De utgjorde tre olika kontrollgrupper.

Ingen skillnad i uppmätta metallmängder kunde konstateras hos de olika försökspersonerna.

Resultaten gav inget stöd åt uppfattningen att oral galvanisk aktivitet ger upphov till förhöjda metallmängder i saliv.

Påståendet att oral galvanisk aktivitet kan förorsaka generella toxiska reaktioner via saliven ifrågasättes.

INTRODUCTION

When metallic restorations are placed in the oral cavity they may take part in corrosive processes. In the electrochemical cells thus created, saliva may act as an electrolyte.

In such cells metal ions can be released from the metal components acting as anodes. This reaction progresses according to the formula



where Me is an atom of the anodic material, Me^{n+} is the cation created with its n number of positive charges and $n\text{e}^{-}$ are the n electrons simultaneously released from the atom.

In this type of intraoral corrosive reactions especially the saliva may be given additional metal ion components with a wide range of possible local as well as general biological effects depending on the characteristics of the metal alloys participating in the reaction.

However, few reports have been made on the metal ion content of human saliva, especially as influenced by restorative treatments including metallic appliances.

Alexiev, Bontchew & Todorov (1973) have studied the silver ion concentrations in saliva collected from 20 patients with a variety of local oral symptoms commonly referred to as oral galvanism. They tried to correlate these concentrations to the number of amalgam restorations present and to the corrosion potential of these restorations.

These authors could not find any correlations at all between the number of restorations, their corrosion potentials and the saliva silver concentrations. In spite of these negative experimental findings, however, a conclusion was drawn that there is a clinical correlation between the number of fillings, their corrosion potentials and the saliva silver concentration on one hand, and the presence of oral discomfort and affections on the other. In the study

described the saliva silver ion concentration was reported to vary between 8.0×10^{-6} and 7.22×10^{-4} per cent by weight.

In studies of the saliva mercury concentration in persons professionally exposed to several mixed mercurials, Joselow, Ruiz & Goldwater (1968) also determined the parotid saliva mercury concentration in a control group of normal working adults not professionally exposed to mercurials. They found this concentration to be below the detection limit ($< 0.05 \mu\text{g}/100 \text{ ml}$) for the control group and to have a mean of $5.0 \mu\text{g}/100 \text{ ml}$ for the group of Hg-exposed workers.

Using thermal neutron activation analysis Arwill, Myrberg & Söremark (1967) studied the saliva concentrations of a variety of elements including copper. In young healthy individuals the saliva copper concentration was found to vary between 0.013 and 0.053 ppm in rest saliva and between 0.015 and 0.052 ppm in stimulated saliva.

Using a reagent-method Golan, Davis & Deller (1971), on the other hand found the mean saliva copper concentration to be $29 \mu\text{g}/100 \text{ ml}$ i.e. 0.29 ppm in normal adults.

Finally Carelli, Colasanti & Picarelli (1974) found the mean saliva zinc concentration to be $1.33 \mu\text{g}/\text{ml}$ in cariesfree subjects and $0.64 \mu\text{g}/\text{ml}$ in cariesprone subjects.

Bearing the above mentioned findings in mind, it was considered worthwhile performing an investigation to determine the saliva concentrations of elements present in dental silver amalgams i.e. of copper, silver, tin, mercury and zinc. It was considered of interest to perform these investigations on subjects with and without amalgam restorations as well as on persons with amalgam restorations giving rise to maximum calculated currents above or below $25 \mu\text{A}$.

MATERIAL AND METHOD

From a group of patients referred to the Dental School in Malmö for measurements of potentials and polarizations of their oral restorations according to the method described by Bergman, Ginstrup & Nilner (1978), three women (A,B and C) age 50,55 and 58 were selected. For all these patients the maximum currents calculated from the results of these measurements were found to be above 25 μ A. Furthermore, the selection of these patients was also performed on the basis that they complained of oral symptoms (most frequently oral smart and burning mouth) often ascribed to oral galvanism. The maximum intraoral currents calculated for the individual patients are given in Table 1.

From the staff of the Dental School in Malmö three women (D,E and F) were selected as a matching control group. As far as age, amount and type of oral restorations were concerned one of the members of the control group showed fairly close resemblance to the matching member of the patient group. None of the women in the control group experienced, however, any kind of symptoms or discomforts from the oral cavity, nor had they ever experienced such symptoms ascribed to oral galvanism.

Further a group of three edentulous women (4,5 and 6) of similar age (50-60 years) were selected from the files of patients of the Department of Prosthetic Dentistry at the Dental School in Malmö.

These women, who had all been edentulous for more than 15 years had previously been successfully treated with complete dentures. No visible metal components could be found in their dentures or oral cavities. None of them had ever experienced symptoms associated with oral galvanism.

Finally, three girls (1,2 and 3) aged 15 were selected from dental registers over persons who had no metallic restorations in their teeth and had never had any such restorations.

The potentials and polarizations of the metallic restorations of the three persons in the matching control group were measured according to Bergman et al (1978). From the results of these measurements maximum intraoral currents were calculated (Bergman et al 1978). The results of these calculations are given in Table 1.

From each of these 12 persons a sample of about 2 ml of whole rest saliva was collected in sterile acid washed tubes. All samples were donated in the morning prior to eating, drinking, smoking and oral hygiene procedures according to Wainwright (1934).

According to the methods described in detail by Amos, Bennett, Matousek, Parker, Rothery, Rowe & Sanders (1975) atomic absorption spectrophotometry (Varian AA6) was then performed on the collected samples to determine the saliva concentrations of Ag, Cu, Hg, Sn and Zn.

Briefly, the Zn-contents were determined with flame atomization and the Hg-contents with flameless technique whilst the Ag-, Cu- and Sn- concentrations were determined in a graphite furnace.

A statistical analysis of the calculated maximum currents given in Table 1 showed no presence of statistically significant (Mann-Whitney U-test: $p > 0.05$) different currents between the persons of the patient group and those of the matching control group.

RESULTS

The respective detection limits and saliva concentrations obtained for the elements studied are given in Figs 1-3. Sn-ions above a detection limit of 0.05 ppm could not be found in any of the samples whilst only one test persons (no 5 in the edentulous group) was found to have a saliva mercury concentration above the detection limit (0.05 ppm for the test persons A,B,C,D,E and F and 0.02 ppm for the rest).

The results given in Figs.1 and 2 clearly show that for Ag and Cu there were no systematic differences in the saliva ion concentration between the patient group and any of the control groups. No statistical analyses were therefore performed on these data.

No signs of differences were observed between the patient group and matching control group. Yet, a non-parametric statistical analysis according to Siegel (1956) was performed on the data obtained for Zn (Fig.3). The result of this analysis did not, however, show the presence of statistically significant differences of Zn-ion concentrations between these two groups (Mann-Whitney U-test: $p > 0.05$).

Using the Spearman rank correlation test (Siegel 1956) a comparison was performed between the calculated maximum currents for test persons A-F and their respective saliva metal concentrations. No statistically significant correlations ($p > 0.05$) could, however, be found between any of these data.

DISCUSSION

The results of recently performed studies show that currents frequently pass between dental metallic restorations at functional as well as proximal contacts (Nilner, Glantz, Ryge & Sundberg 1981 a and Nilner, Glantz & Zöger 1981 b). Further, when participating in the generation of such currents, amalgam restorations frequently serve as the anodic component (Nilner et al 1981 b).

"In vitro" studies of corrosive processes have shown release of copper from dental amalgams (Espevik 1977) and cadmium from dental soldering alloys (Bergman & Ginstrup 1975).

Few clinical studies have been presented in this field. Those reported have, however, shown the saliva ion concentration to be low for amalgam components (Arwill et al 1967, Joselow et al 1968, Gollan et al 1971, Alexiev et al 1973 and Carelli

et al 1974).

Studies of the Hg-concentrations in tissues in permanent contact with or close relation to amalgam restorations have, on the other hand, shown increased Hg-values both in the pulp (Möller 1978) and the periodontium (Fréden, Helldén & Milleding 1974).

Further, it has frequently been considered possible for intraoral electrochemical corrosive processes to cause discomfort, pain and oral mucosal lesions (Schriever & Diamond 1952, Mumford 1960, Frykholm 1961, Bergman et al 1978 and Banoczy, Roed-Petersen, Pindborg & Inovay 1979). In oral corrosive processes amalgam is often found to be the anodic component where a certain breakdown may take place. The most likely vehicle for transportation of the ions released at corrosion is saliva. Therefore it was considered worthwhile studying the saliva concentrations of ions possibly released from amalgam surfaces during electrochemical corrosion.

The results of the previously reported studies of saliva metal ion concentrations indicate that the methods used have to possess high precisions. This fact excluded the use of simple reagent methods and formed the basis for the decision to use atomic absorption spectrophotometry. As this is not only a method of high analytical precision but also an expensive, complicated and time consuming one, only one analysis per person and type of ion was carried out. Bearing in mind, however, that the method used also has a high degree of accuracy (Amos et al 1975) and that only small and statistically insignificant interindividual variations were found in the studied saliva ion concentrations, the dimension of this study was considered sufficient for valid conclusions to be drawn as far as the saliva concentrations of Ag, Cu, Hg, Sn and Zn were concerned.

Of the patient group, only women were selected. Consequently, only women were selected for the matching control group. There is no indication that

the saliva ion concentrations of Ag, Cu, Hg, Sn and Zn should differ systematically between males and females and it is highly unlikely for the release of ions to show sexrelated variations at intraoral corrosion. Yet as a consequence of the outcome of the selection of patients, it was decided only to select females for the edentulous group and the group of teenagers with no history of oral metallic restorations.

The absolute majority of the totally more than 200 persons, who so far have been referred to the Dental School in Malmö for investigation of possible correlations between oral discomforts and pain on one side and oral galvanism on the other, have been women. In relation to the above mentioned facts and the present state of this clinical problem it was therefore thought justified only to study females.

The results of the performed analyses show that the saliva ion concentrations are at a low and uniform level for all studied groups and ions. Thus, the overall conclusion of this study was to render no support to the theory that increased intraoral galvanic action of amalgam restorations influences the saliva concentrations of Ag, Cu, Hg, Sn and Zn. On the contrary, bearing in mind the results of the two groups with no metallic restorations it is not even likely that the presence of dental amalgams has any influence on the saliva concentrations of the studied ions. Rather, if these concentrations are at all higher than essential levels, they must be the consequence of the general environmental conditions and not of local oral ones. Whether or not the saliva ion concentrations found are inflated is an interesting problem, which, however, has not been included in the aims of this study. A separate study of this problem creates many practical difficulties as it must include the formation of a new control group of subjects without metallic restorations and without a history of exposure to urban environments.

In this context it should be emphasized that the above mentioned conclusions are only valid for dental conditions similar to those existing in Sweden i.e. where almost invariably all mercury and amalgam alloys pass adopted standards and where amalgams are prepared and handled by trained dentists and dental assistants.

For the separate ions studied, in the majority of cases, atomic absorption spectrophotometry could not detect Hg-ions in saliva. This corresponds closely to the report by Joselow et al (1968) for persons without occupational exposure to mercurials but is somewhat contradictory to reports by Möller (1978) on the Hg-content in the pulpal tissues of teeth with freshly made amalgam restorations, and by Fredén et al (1974) on this content in periodontal tissues in contact with amalgams. One possible reason for these differences could be that release of Hg is increased at interfaces between amalgam restorations and solid tissues as compared with liquid ones like saliva. Another possible reason could be that the release of Hg-ions is only marked during a relatively short period of time after the insertion of an amalgam restoration. The mercury ions released into saliva are then transported away while at the interface with soft and hard tissues it is possible that they are retained.

Sn-ions could not be detected in any of the saliva samples. The chemistry of dental amalgams is such that, if present, Sn-ions will comparatively easily be released at amalgam interfaces. The negative finding for Sn is thus an additional indication that the metal components of saliva are not, to any marked extent influenced by the presence of amalgam restorations in the oral cavity.

The saliva concentrations of Cu as found are in line with those reported by Arwill et al (1967) whilst the concentrations of Ag and Zn are somewhat lower than those reported by Alexiev et al (1973) and

Carelli et al (1974) respectively. These small but insignificant differences are probably caused by differences in the precision of the analytical methods used.

In conclusion, the presence of amalgam restoration was not found to have any noticeable influence on saliva metal ion concentrations. Neither could any correlations be found between oral galvanic activity, as expressed by the calculated maximum currents, and the studied saliva ion concentrations. The results of this study therefore question the suggestions that increased oral galvanic action may cause general toxic reactions through the saliva.

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Table 1. Calculated maximum intraoral currents for three female patients with certain oral symptoms (A,B and C) and a matched control group (D,E and F).

	Patient					
	A	B	C	D	E	F
Current	25.74	26.33	44.36	10.79	4.70	17.00

LEGENDS

- Fig. 1 Silver concentrations in whole rest saliva from three female patients (A,B and C) with certain oral symptoms, their matched control group (D,E and F), three edentulous females (4,5 and 6) and three teenaged girls (1,2 and 3) without metallic restorations (d.l. = detection limit)
- Fig. 2 Copper concentrations in whole rest saliva from three female patients (A,B and C) with certain oral symptoms, their matched control group (D,E and F), three edentulous females (4,5 and 6) and three teenaged girls (1,2 and 3) without metallic restorations (d.l. = detection limit)
- Fig. 3 Zinc concentrations in whole rest saliva from three female patients (A,B and C) with certain oral symptoms, their matched control group (D,E and F), three edentulous females (4,5 and 6) and three teenaged girls (1,2 and 3) without metallic restorations (d.l. = detection limit)

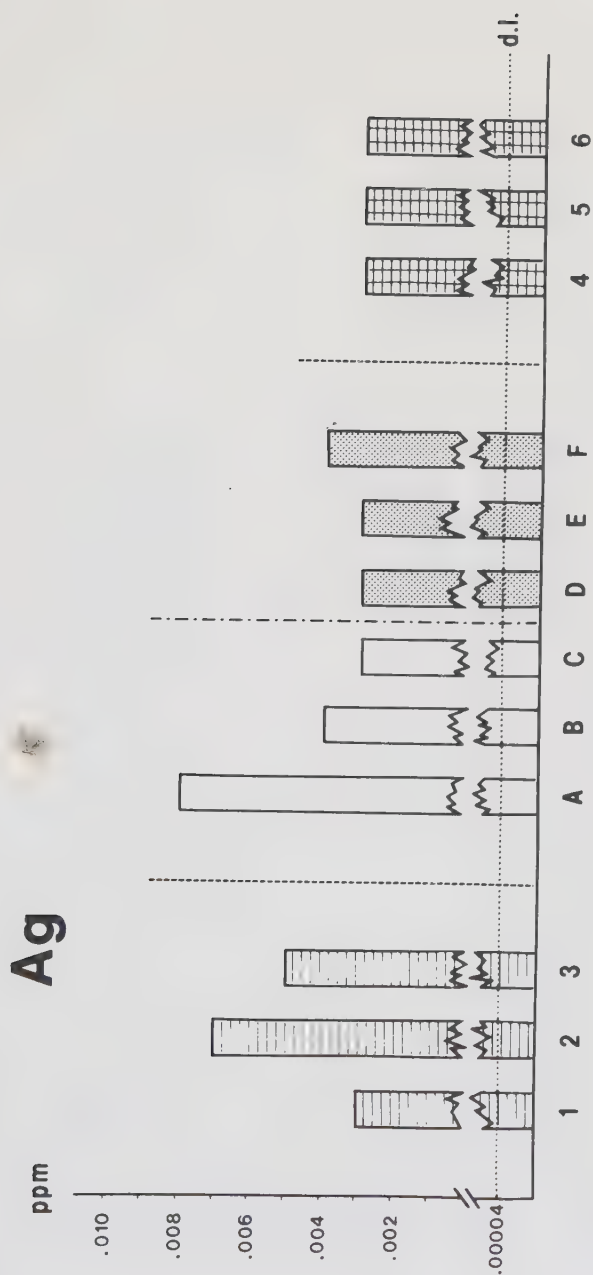


Fig. 1.

Cu

ppm



Fig. 2.

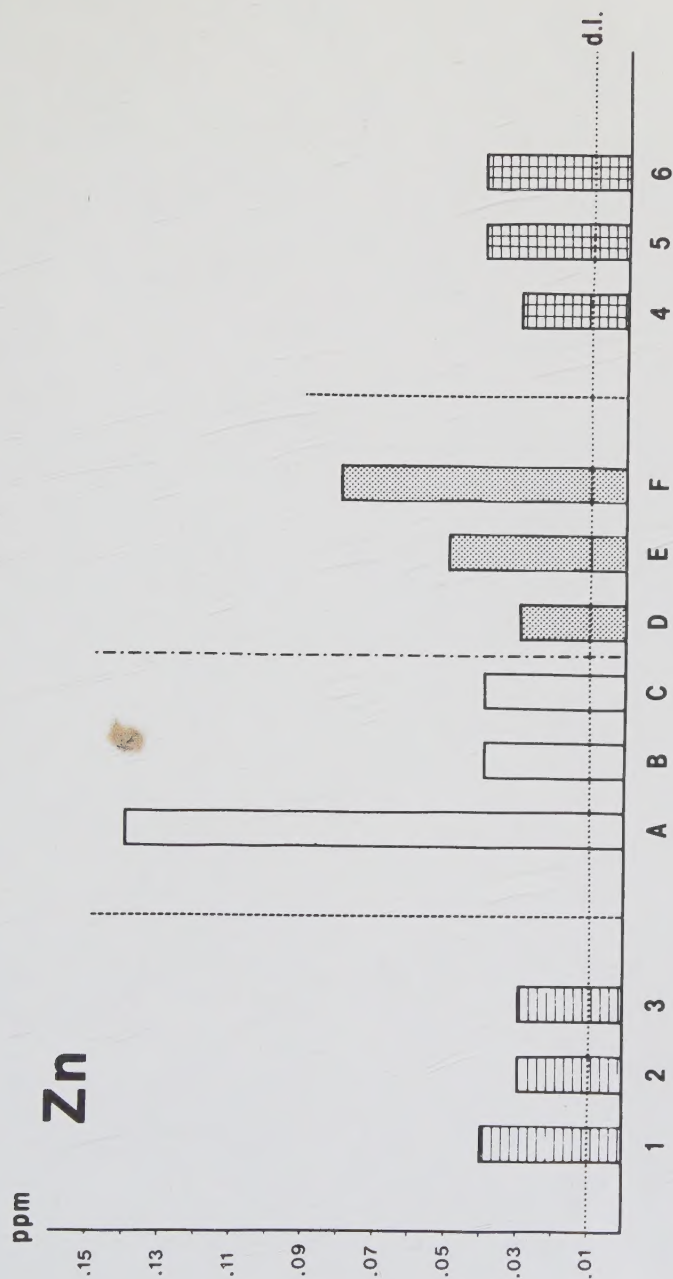


Fig. 3.

